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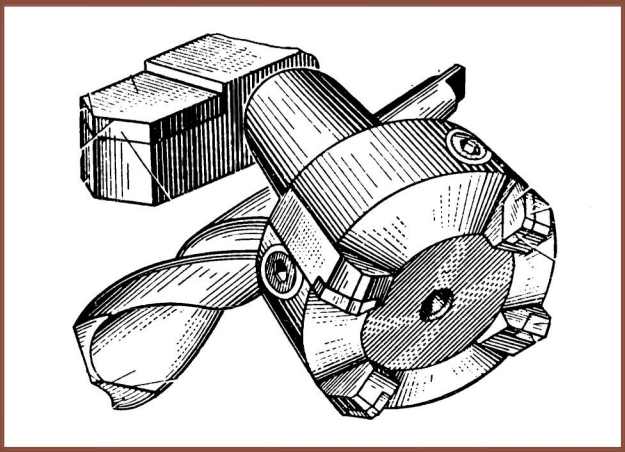
SINTERED METAL CARBIDES



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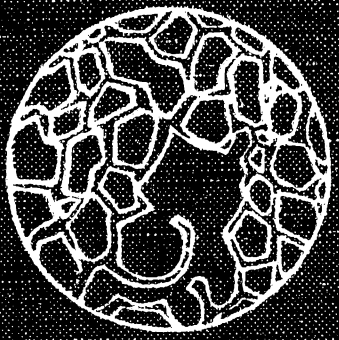

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ИЗДАТЕЛЬСТВО «МЕТАЛЛУРГИЯ» МОСКВА

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SINTERED METAL CARBIDES

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The Russian Alphabet and Transliteration

Аа a	Кк k	Хх kh
Бб b	Лл l	Цц ts
Вв v	Мм m	Чч ch
Гг g	Нн n	Шш sh
Дд d	Оо o	Щщ shch
Ее e	Пп p	ъ ’’
Ёё ë	Рр r	ы y
Жж zh	Сс s	ь ’
Зз z	Тт t	Ээ e
Ии i	Уу u	Юю yu
Йй y	Фф f	Яя ya

На английском языке

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Foreword

Materials of high-strength and great resistance to wear used in different branches of industry are essential to the rapid development of technology, mechanization of production processes, and improvement in quality of products.

The introduction of sintered metal carbides has caused a revolution in many industrial branches. Thus, in the iron and steel industry, sintered metal carbides (also called metal-powder products) have replaced carbon and high-speed cutting steels. The wear resistance of cutting tools and the cutting speeds, as well as the efficiency of labour, have been greatly increased due to the use of sintered carbides. The quality of surface finish and the accuracy of dimensions have also been improved.

In recent years, the use of sintered metal carbides has grown extensively and the demand for better quality has increased.

Techniques for the production of new grades of strong and wear-resistant metal-powder products have been developed and are already used in the metal-powder industry. New processing equipment has also been designed and produced. All this has led to a certain complication of the production process and there has arisen a demand for a higher qualification of the workers and engineers engaged in the production of sintered metal carbides.

This book is intended as a textbook for vocational schools for training new workers and specialists. It can also be used as a practical aid by workers employed in this field.

The book describes the manufacturing process for the production of sintered metal carbides, from powder preparation to sintering of products; methods of testing finished products; machining and use of sintered metal carbides.

Special attention is paid to the description of processing equipment and of methods of procedure.

Chapters I-IV were written by V.I. Dusev, Candidate of Technical Sciences; Chapters V and VII, by engineer N. I. Romanova; Chapter VI, by N. I. Romanova together with engineer T. A. Lifshitz; Chapters VIII, X, XI, by P. G. Chekulaev, Candidate of Technical Sciences, Chapter IX, by engineer T. A. Lifshitz; Chapter XII, by engineer M. N. Kurdov.

Preface

Only a little over 40 years have passed since the first sintered metal carbides were produced, and now they are so extensively used in production that it is difficult to name any branch of industry that does not use powder-metal products.

The use of sintered metal carbides for dies has paved the way to extensive use of punching techniques for a multitude of parts on automatic presses. If in the past a die made of the best alloyed steel, was adequate for not more than 10,000 products, today a die of sintered metal carbide may produce several hundreds of thousands and sometimes, over a million products. Sintered metal carbides have found wide use in the manufacture of drawing tools. About 1000 kg of steel wire can be drawn through a drawing plate made of sintered metal as compared with 50-60 kg for steel draw-plates.

In the mining industry, the use of sintered metal carbides for strengthening drilling tools has made possible an increase in the efficiency of drilling and the wear resistance of drills and bits, and has solved the problem of drilling of strong and very hard rocks.

Sintered metal carbides are produced from carbides of refractory metals in combination with more easily fusible metals which are used as the bonding metal.

The hard alloys are made by sintering in a protective atmosphere a mixture of powdered carbides and the bonding metal. That is why they are called metal-powder products or sintered metal carbides.

The beginning of powder metallurgy goes back to antiquity. When ancient habitations are dug up, weapons are found that are decorated with plates made of powdered

gold and other noble metals. In one of the squares of New Delhi, there is an iron column whose age exceeds 2000 years. This column is made by a method which is very similar to that of the sintered metal process.

However, extensive industrial use of powder metallurgy took place much later. The development of powder metallurgy is connected with the name of the Russian scientist P. G. Sobolevsky who as far back as 1825 together with V. V. Lyubarsky developed a method of manufacturing platinum products by pressing platinum powder in the cold state, with subsequent sintering of the pressed material.

The manufacture of sintered metal carbides was begun a century later. The first sintered metal carbides, made of tungsten carbide and cobalt, were produced in 1923-1925 by the German firm Osram according to patents issued to Shretter. In 1926 Krupp began the industrial production of Widia alloys. At the 1927 Leipzig Fair, a Widia alloy was demonstrated, containing 94 per cent WC and 6 per cent Co.

In the Soviet Union, sintered metal carbides have been produced since 1929-1930.

Today, many plants in the Soviet Union are producing sintered metal carbide materials. Large specialized research institutes and various institutions have been established where theoretical and practical problems concerning powder metallurgy are being solved.

The development of powder metallurgy owes a great deal to the work of G. A. Meyerson, V. I. Tretyakov, V. S. Rakovsky, M. Yu. Balshin, G. S. Kreimer, Ya. I. Frenkel, V. A. Ivensen, I. N. Chaporova, Ya. V. Gegusin and other Soviet scientists.

CHAPTER I

Raw Materials for Production of Sintered Metal Carbides

1.1. Main and Auxiliary Materials

The materials used for the production of carbides (hard alloys) are, mainly, the following:

(a) tungstic anhydride, ammonium para-tungstate, tungstic acid;

(b) cobalt oxide;

(c) titanium oxide;

(d) carbon black.

These materials enter into the composition of the alloy, therefore they are called the main or starting materials.

The materials required for manufacturing the product, but not contained in the product itself are called auxiliary materials.

In production of carbides the auxiliary materials are: ethyl alcohol, hydrogen, graphite, petrol, paraffin, etc.

The starting materials required for producing sintered metal carbides, must be very pure since even a small amount of impurities considerably worsens the quality of the alloys.

1.2. Production of Tungstic Anhydride and Ammonium Para-Tungstate

Tungstic anhydride and ammonium para-tungstate are obtained at chemical plants from concentrated tungsten ores.

The main tungsten ores are wolframite and scheelite.

Wolframite (Fe, Mn) WO_4 is a mineral of black, brown or red-brown colour with a metallic lustre. It is contained in ores in very small amounts.

Scheelite $CaWO_4$ is a white, sometimes yellow, grey or brown mineral contained in ores in small amounts.

The content of tungstic anhydride WO_3 in ores ranges from fractions of one per cent to several per cent. Besides tungsten minerals, tungsten ores contain minerals of molybdenum, tin, copper, iron, and many rare-earth elements.

The richest deposits of tungsten ores are found in the USSR, China, South Korea, Burma, the USA, Spain, and Portugal.

Since tungsten ores contain a very small amount of tungsten, they have to be treated at special concentration plants. The ores delivered to the concentration plant, while being processed, are classified into:

(a) concentrated ore known as tungsten concentrate with a tungsten content of 60 up to 70 per cent (in terms of WO_3);

(b) barren rock (tailings) which practically contains no tungsten.

The process of concentration is very labour-consuming. To obtain one ton of tungsten concentrate, it is necessary to process about 36 tons of ore with a 2 per cent tungsten content. Therefore the concentration plants are usually built close to the tungsten deposits.

The tungsten concentrates are processed at chemical plants to obtain pure tungsten compounds: tungstic anhydride, tungstic acid, and ammonium para-tungstate. The tungsten concentrates are also processed by metallurgical methods to produce ferrotungsten, which is widely used for manufacturing high-grade tool steels.

The tungsten concentrates delivered for conversion into tungstic anhydride, tungstic acid and ammonium para-tungstate to be subsequently used for the production of carbides and tungsten filaments for the electric lamp industry have the following standard composition, per cent:

Tungstic anhydride, min. . . .	55-60
Admixtures, max.:	
tin	1.0
sulphur	0.5-1.0
molybdenum	0.3
arsenic	0.10
copper	0.15-0.20
phosphorus	0.10-0.30
antimony	0.05

The moisture content should not exceed 6% in scheelite concentrates, and 2% in wolframite concentrates.

At chemical plants, tungsten concentrates are processed by various methods with the result that the tungsten of the concentrate goes into a water-soluble chemical compound. The aqueous solutions of tungsten compounds are thoroughly cleaned of foreign substances, and then tungsten salts, acids, or oxides are obtained from them.

For processing scheelite concentrates, the industry uses the following methods:

(a) sintering of the concentrate with soda ash (Na_2CO_3) and silica sand and subsequent treatment of the sintered mass with water;

(b) treatment of crushed concentrates with solutions of soda ash in autoclaves at high temperatures and pressures.

When processing the wolframite concentrates, the following methods are used:

(a) sintering of the concentrate with soda ash and subsequent treatment of the sintered mass with water;

(b) treating of crushed concentrates with aqueous solutions of caustic soda (NaOH).

All these methods are termed processes of concentrate decomposition, because tungsten minerals are converted into water-soluble compounds. In all cases of concentrate decomposition, aqueous solutions of sodium tungstate Na_2WO_4 are obtained, from which impurities are removed by various methods.

The relatively pure solutions of sodium tungstate thus obtained are further purified. This process includes the following operations:

1. Settling of synthetic scheelite. The sodium tungstate solutions are treated with aqueous solutions of calcium chloride which are poured into solutions of sodium tungstate. In this case, the following reaction takes place:

$$Na_2WO_4 + CaCl_2 = CaWO_4\downarrow + 2NaCl$$

As a result, $CaWO_4$ precipitates in the form of white crystals, other admixtures remaining in the solution. The precipitate is thoroughly washed with water until no NaCl remains in it.

2. Preparation of tungstic acid. The precipitate of synthetic scheelite is treated with hot hydrochloric acid, the

following reaction taking place:

$$CaWO_4 + 2HCl = H_2WO_4 + CaCl_2$$

The white precipitate of $CaWO_4$ turns yellow, taking the colour of tungstic acid. The acid is washed several times with hot distilled water and dried in a centrifuge, where most water is separated. Then the tungstic acid is calcined in a rotary kiln, where it decomposes as follows:

$$H_2WO_4 \rightarrow WO_3 + H_2O$$

The tungstic anhydride WO_3 thus obtained is packed into multilayer bags of strong paper.

Calcining of tungstic acid is a critical operation. To obtain tungstic anhydride of a certain grain size, it is essential that the temperature of calcining be kept at the stipulated level. At a temperature of 100 C above normal the anhydride is obtained as very coarse grains, while at a temperature below normal the powder becomes too fine and a complete decomposition of tungstic acid is hard to achieve.

The preparation of very pure tungsten compounds requires additional purifying operations. The first of such operations is the production of ammonium tungstate solutions by treating tungstic acid with an aqueous solution of ammonia:

$$H_2WO_4 + 2NH_4OH = (NH_4)_2WO_4 + 2H_2O$$

In this case all tungstic acid crystals dissolve, while the impurities (silicic acid, iron compounds, aluminium and other substances) are not soluble in ammonia and thus remain solid.

After settling, the ammonia solutions are separated from the residue by decantation and filtration in a centrifuge.

However, due to the reversible character of reactions, small amounts of impurities remain in the solution. For further purification of the tungsten compound, the solutions of ammonium tungstate are heated in order to concentrate them by evaporation with the result that the ammonium para-tungstate settles down and the admixtures remain in the mother liquor. The ammonium para-tungstate residue is washed first with weak ammonia, then with distilled water, and then centrifuged. The crystallic precipitate of ammo-

monium para-tungstate is desiccated in steam dryers, then packed into cotton bags and wooden boxes.

Ammonium para-tungstate has a complex chemical formula $5(NH_4)O \cdot 12WO_3 \cdot xH_2O$. Evaporation at temperatures above 50 C yields laminar crystals of ammonium para-tungstate of a composition of $5(NH_4)O \cdot 12WO_3 \cdot 5H_2O$. If the crystallization takes place at lower temperatures, acicular crystals fall out. The acicular crystals have a composition of $5(NH_4)O \cdot 12WO_3 \cdot 11H_2O$.

Ammonium para-tungstate prepared by such methods is the commercial product used for production of carbides and some grades of metallic tungsten.

To obtain chemically pure tungstic acid for preparation of tungsten filaments for the electric lamp industry, the ammonium para-tungstate is treated with chemically pure hydrochloric acid. The tungstic acid H_2WO_4 thus obtained is washed several times with distilled water, dried and delivered for production of tungsten wire.

1.3. Production of Cobalt Oxide

The cobalt oxide used in the production of carbides is a mixture of cobaltous oxide CoO and cobaltic oxide Co_2O_3, obtained from metallic cobalt or from commercial cobaltic hydroxide $Co(OH)_3$.

Large deposits of cobalt ores are found in Congo, Zambia, Canada and Cuba. Besides, there are many smaller deposits of cabalt ores.

There are three main types of cobalt ores:

1. Cobalt arsenide ores (the main minerals are skutterudite ($CoAs_3$) and smaltine (Co, Ni)As_3.

2. Cobalt sulfide ores containing minerals of copper, iron, and nickel.

In sulfide ores, cobalt is an impurity. For example, the mineral pentlandite (NiFe)S_2 contains 0.5 to 3 per cent cobalt. Most often cobalt is found in pyrite FeS_2 (from fractions of one per cent to 3 per cent). In some sulphide ores nickel is accompanied by copper, in the form of chalcopyrite (Cu, Fe)S_2, and cobalt. Usually such sulfide ores contain 0.3 to 5.5 per cent Ni, up to 2.5 per cent Cu and up to 0.2 per cent Co.

Oxidized cobalt ores contain cobalt in the form of asbolane $m\,(Co, Ni)O \cdot MnO_2 \cdot nH_2O$, a mineral which consists of oxides of cobalt, nickel, and manganese. Asbolane often accompanies nickel and magnesium silicates in the oxidized cobalt ores. Minerals of this type are called garnierite and revdinskite. Oxidized ores usually contain, in addition to iron hydroxides, 0.9 to 1.5 per cent nickel and up to 0.15 per cent cobalt.

Cobalt is produced commercially from cobalt or cobalt-copper ores or as a by-product of nickel ores containing cobalt as a permanent component. The cobalt content in cobalt and cobalt-copper ores is up to 1 per cent, and with side recovery the content is up to a few tenths and even hundredths of one per cent.

The metallurgy of copper-nickel sulphide ores containing cobalt is in many respects similar to pyrometallurgy of copper. Ores with a total content of copper and nickel of more than 5 per cent are considered rich; they are used directly for smelting. Poorer ores are first concentrated. The ores and concentrates are smelted to obtain copper-nickel matte (an alloy of sulphides of iron, copper, nickel, and cobalt). The melted matte is bessemerized with quartz added to it. The remainder of iron is oxidized and slagged with quartz. The principal product of bessemerization is an alloy of sulphides of copper, nickel, and cobalt, known as converter matte. The converter matte is reprocessed to extract copper, nickel, and cobalt.

The main difficulty in the extraction of nickel and cobalt from oxidized ores lies in their separation from iron.

The method most extensively used at present for processing of oxidized nickel and cobalt ores containing iron is based on the different affinity of iron and nickel with oxygen and sulfur. During the process of smelting of these ores, gypsum is added to them and the nickel and cobalt are converted into sulphides. The matte obtained is an alloy of CoS, NiS, FeS sulphides, the bulk of iron being removed with the slag. The nickel matte contains up to 65 per cent Fe, which is further separated from nickel by bessemerizing the liquid matte; in the process, iron is oxidized and slagged with quartz.

The white nickel matte (converter matte) is further processed to obtain nickel. The converter slag, rich in nickel, returned into the converter for resmelting. Cobalt, together with the remainders of iron, is slagged at the end of the converter process. This part of slag is collected separately and reprocessed to obtain cobalt in the form of commercial cobalt hydroxide.

Metallic cobalt powders for carbide fabrication are made from commercially pure metallic cobalt available in the form of roundles or granules, or from pure cobalt oxide obtained by oxidizing metallic cobalt, or else from commercially pure cobalt hydroxide.

Metallic cobalt is dissolved in nitric or hydrochloric acid. The acid solutions of cobalt chloride thus obtained are neutralized until they are neutral to methyl red. Air is blown through the solution to oxidize ferrous compounds into ferric ones, and after the blowing hydrogen peroxide H_2O_2 is added to assure complete oxidation. To remove iron from the solution, soda ash is added till a weak alkaline reaction takes place. Then iron falls out in the form of iron hydroxide and basic salts. After settling down of iron-containing residue the solution is filtered. If the manganese content is too high (over 0.1 per cent), sodium hypochlorite (NaOCl) is added to the solution to remove manganese.

Next, cobaltous oxalate CoC_2O_4 is prepared. A solution of cobalt chloride cleaned of iron and manganese is heated to 80°C. The heated solution containing a small quantity of iron is treated with dry pure oxalic acid $H_2C_2O_4$. The reaction mixture is stirred, then dry ammonium oxalate $(NH_4)_2C_2O_4$ is added to it till complete settling occurs. After settling down of the cobalt oxalate, the mother liquor is decanted and the cobalt oxalate residue is removed to a suction filter, where it is washed several times with hot distilled water or steam condensate. The washed cobalt oxalate is then analysed by the spectrochemical method for calcium and sodium content. If the content of these elements is too high, the washing of the cobalt oxalate is continued. The washed out cobalt oxalate is dried in a centrifuge, then desiccated, and calcined at 350-400°C till a homogeneous soft black powder of cobalt oxide is obtained.

The powder of cobalt oxide should have the following composition:

Element	Co	Na	Ca	Fe	Ni	Mn	O
Content, %	$\geqslant 70$	$\leqslant 0.018$	$\leqslant 0.01$	$\leqslant 0.06$	$\leqslant 1.5$	$\leqslant 0.09$	$\leqslant 0.7$

The bulk density of powder should not exceed 0.75 g/cm^3.

Another raw material for obtaining cobalt oxide is commercial cobalt hydroxide. Cobalt hydroxide is first reduced by carbon black or hydrogen in muffle electric furnaces at a temperature of 600 to 700 C, pushing gradually cast-iron boats (trays) filled with cobalt hydroxide through the furnace muffle. The sintered mass of reduced metallic cobalt is dissolved in hot hydrochloric acid in an iron reactor with the walls lined with silica tiles. The solution of cobalt chloride is clarified and poured out while hot into a rubberized iron vessel. Then the solution is neutralized with soda ash. To remove iron impurities, compressed air is blown through the solution and hydrogen peroxide added, the iron falling out into the residue. Then the solution of cobalt chloride is again clarified and filtered. Cobalt oxalate (and cobalt oxide obtained from it) is produced in the same way as in the above process.

The low content of cobalt in ores makes pyrometallurgical methods of their processing very complicated and labour-consuming, therefore the cost of cobalt production is one of the most expensive items of carbide production.

1.4. Production of Titanium Oxide

Titanium ores are abundant, but not all of them are suitable for concentration to a level at which further processing is economically justified. The following titanium ores are known: rutile, titanomagnetite, ilmenite, perovskite ($CaO \cdot TiO_2$) and titanite ($CaO \cdot TiO_2 \cdot SiO_2$). Titanomagnetites contain TiO_2 and Fe_2O_3. Considerable segregations of titanium are found chiefly in the form of rutile (TiO_2) and ilmenite $FeO \cdot TiO_2$.

High-quality raw materials for the production of titanium oxide are the Indian, Malay and Ukrainian (USSR) ilmenites. Leaner, but suitable for production of titanium oxide are the deposits of ilmenite found in the USA, Canada,

South America, Norway, Finland and the USSR (the Urals). Table 1.1 shows the chemical composition of some ilmenite concentrates.

Table 1.1

Approximate Composition of Ilmenite Concentrates

Oxide	Origin of the concentrate			
	Norway	Ukraine	Urals	Malaya
	Content of oxides, per cent			
TiO_2	44-66	52	42	54
FeO	36	26	37	29
Fe_2O_3	10	18	10	10
SiO_2	3	1	3	1
Al_2O_3	0.5	1	2.5	1
MnO	0.3	0.6	0.8	3
MgO	3	0.8	2	0.1
CaO	—	0.6	2	—
V_2O_5			0.3	0.003
Cr_2O_3	0.006	0.01	0.01	0.02

Titanomagnetites are magnetites penetrated with ilmenite and containing up to 25 per cent TiO_2. Concentration of titanomagnetite ores yields ilmenite concentrates for the titanium industry and for production of ferrotitanium.

Use is made of a titanomagnetite concentrate of the following percentage composition: 44 TiO_2, 16.8 Fe_2O_3, 31.4 FeO, 0.3 V_2O_5, 1.6 Al_2O_3, 0.7 MnO, 0.6 CaO, 2.8 MgO, 1.8 SiO_2, 0.15 P_2O_5.

Besides being used as a raw material for production of carbides, titanium oxide is used in the paint and varnish industry as a white pigment, in the rubber industry as a filler, in the viscose industry for delustering artificial silk. In addition, titanium oxide is used for manufacturing refractory glass, glazes, and enamels. Titanium is used as a deoxidizing agent and an alloying metal. It is introduced into steel as ferrotitanium. Titanium improves the mechanical properties of steel and increases its resistance to wear and corrosion. Metallic titanium began to be used only

during the last 10-15 years, when the progress of technology made it possible to obtain the metal of high purity. It is used for manufacturing sheet, wire, welded and seamless pipes, etc. Titanium facilitates the forming of fine-grained alloys, so it is introduced into some aluminium bronzes, special brasses, aluminium and aluminium-magnesium alloys. Titanium oxide is also used for manufacturing titanium and tungsten carbides.

Titanium oxide is mainly produced from ilmenite concentrate. A method of processing with sulphuric acid is used extensively, in which ilmenite concentrate is decomposed with strong sulphuric acid, the mixture being stirred with compressed air.

When the concentrate interacts with sulphuric acid, the following chemical reactions of sulphate formation take place:

$$TiO_2 + H_2SO_4 \rightleftarrows TiOSO_4 + H_2O$$
$$FeO + H_2SO_4 \rightarrow FeSO_4 + H_2O$$
$$Fe_2O_3 + 3H_2SO_4 \rightarrow Fe_2(SO_4)_3 + 3H_2O$$

The reactions proceed very violently and take but a few minutes. Almost all water is evolved from the reaction mixture in the form of water vapours. When the reaction ends, the supply of compressed air is discontinued. Then the mixture of sulphates is cooled and lixiviated with water acidified to avoid the formation of iron hydroxide. The lixiviating process lasts 3 to 5 hours. To reduce the ferric compounds contained in the solution into ferrous compounds, shearings of black sheet steel are charged into the apparatus.

The reduction takes place according to the reactions:

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$
$$Fe_2(SO_4)_3 + H_2 \rightarrow 2FeSO_4 + H_2SO_4$$

Summarizing the reactions, the following equation is obtained:

$$Fe + Fe_2(SO_4)_3 \rightarrow 3FeSO_4$$

Reduction of titanium sulphate continues according to the equations:

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$
$$2TiOSO_4 + H_2SO_4 + H_2 \rightarrow Ti_2(SO_4)_3 + 2H_2O$$

After reduction the solution contains ferrous sulphate. To get rid of iron, the solution is heated. At a temperature of 45°C crystals of ferrous sulphate $FeSO_4 \cdot 7H_2O$ begin settling down. They are separated from the solution in a continuous vacuum crystallizer. Crystals of ferrous sulphate are separated and washed with water in centrifuges. To recover titanium oxide, the solution is evaporated in vacuum and then the titanium sulphate is subjected to hydrolysis, as a result of which a white precipitate of metatitanic acid $TiO_2 \cdot HOH$ or H_2TiO_3 falls out of the solution. The precipitate of metatitanic acid is filtered, iron and other impurities are washed off it on drum-type vacuum filters. The washed metatitanic acid is delivered by belt and screw conveyers into a rotary furnace for calcination. The metatitanic acid H_2TiO_3 is calcined for 6-8 hours at about 1000°C to obtain titanium oxide for metallurgy. The furnace may be heated with fuel oil or gas cleaned of tar and dust.

The titanium oxide obtained is subjected to dry crushing in an annular roll mill, operating in a closed cycle with an air separator. The material used for the production of carbides should contain a minimum of 99.5 per cent titanium oxide and a maximum of 0.10 per cent Fe_2O_3, 0.40 per cent SO_4, 0.06 per cent P_2O_5, and 0.20 per cent SiO_2.

The residue of wet screening through a 0.06-mesh sieve should not be more than 1 per cent.

Titanium oxide is supplied in multilayer paper bags weighing not more than 40 kg.

Some carbide producing plants, before using titanium oxide, subject it to calcination at about 700°C in an electric furnace in stainless steel trays continuously moved through the furnace. The process of calcination removes the remains of phosphorous anhydride P_2O_5, and sulphurous-acid anhydride SO_2 and sulphuric anhydride SO_3.

1.5. Production of Carbon Black

Lamp or gas black is used in the production of tungsten powders, tungsten carbides and combined titanium-tungsten carbides. Until recently, the production of sintered metal carbides made use mainly of lamp black. Today, the rigorous requirements to carbides quality prohibit the use

of lamp black which contains a large amount of impurities: up to 1 to 1.5 per cent sulphur, up to 0.1 per cent ash, and up to 1.5 per cent volatiles. Gas black offers higher purity.

Carbon black is a product of incomplete combustion or thermal decomposition of carbonic substances. It is a very fine black powder consisting of highly dispersed particles of pure carbon. Lamp black is prepared by burning oil products (solar distillate, ligroin, etc.) in wick lamps with an insufficient air supply. The soot formed is lamp black. It is deposited on moving metal surfaces and removed by special devices, while the air-suspended soot is precipitated in filters. Carbon black is packed into dense paper bags. To prepare gas black, natural gas is burnt in chambers with an insufficient air supply.

Finished lamp black should contain a maximum of 0.5 per cent of moisture as determined by loss in mass after heating to 105-110 C and 0.10 per cent of ash. The residue after screening through a 0.15K-mesh sieve should not exceed 0.005 per cent.

CHAPTER II

Production and Properties of Powder Materials

Powder metallurgy makes various articles out of metallic powders by sintering. The quality and properties of the sintered products greatly depend on the quality and properties of the powder.

The properties of the powder, i.e. chemical composition, size, shape, and surface conditions of the particles, mouldability and other characteristics, depend, in turn, on the initial materials and the production methods.

The methods of powder production may be divided into three large groups: mechanical, chemical, and physico-chemical methods.

The mechanical methods are based on progressive crushing and grinding of the starting materials. Crushing is done in crushers of various design: jaw crushers, roll crushers, cone crushers, and hammer crushers. Grinding is performed in ball, hammer, vortex, and vibration mills. Another method used is atomization of a jet of molten material with steam or compressed gas.

The choice of the method of powder production depends on the properties of the starting material and on economical factors.

2.1. Elements of Crushing and Grinding

The efficiency of crusher operation is estimated in terms of the energy consumed per 1 kg or 1 ton of finished product. The energy consumption per ton of product depends on the type of machine used and on the fineness of grinding.

The fineness factor is the ratio of the initial diameters d_i of particle of the material to their final diameters d_f after

grinding

$$i = \frac{d_i}{d_f}$$

The higher the fineness of grinding, the higher the energy consumption per ton of product, therefore every type of machine has a certain limit of grinding fineness beyond which its use becomes impracticable. Thus, for example, the limiting fineness factor of jaw crushers is 5, that of hammer crushers is 8. For mills the limit may reach 1000.

Thus, when choosing the type of machine for grinding, the properties of the materials to be ground and the fineness required should be taken into account.

Depending on the physical properties of the material, the following modes of grinding are generally chosen.

Material	Mode of grinding
Hard and brittle	Crushing or impact
Hard and tough	Crushing
Brittle, medium hard	Impact, rolling, or attrition
Tough, medium hard	Attrition or attrition with impact

According to the granularity of starting and finished materials, the grinding process may be divided into coarse, medium and minute crushing, and fine and ultrafine grinding.

Coarse and medium crushing is usually done in jaw, cone, and hammer crushers. The recommended fineness factor for crushers of these systems is given in Table 2.1.

Table 2.1

Fineness Factors Obtainable in Coarse and Medium Crushers

Crusher	Fineness factor	
	recommended	maximum
Jaw crusher	3-4	5
Cone crusher	3-4	5
Hammer crusher	4-5	8

Minute crushing, as well as fine and superfine grinding are performed in roll and hammer crushers, as well as in impact and other types of mills.

Table 2.2

Fineness Factors and Sizes of Discharged Products in Various Types of Mills

Mill type	Fineness	Size of discharged product, mm	Mill type	Fineness	Size of discharged product, mm
Rolling	10-15	2-3	Ball	50-100	0.05-0.005
Crusher	10-15	1-0,8	Ring	60-80	0.01
Single-tractor hammer	10-15	0.5-0.2	Vibrating	80-100	0.05-0.005
Vortex	30-100	0.25-0.08	Colloid	Up to 1000	$1 \cdot 10^{-4}$

The fineness factors and the sizes of the product discharged from various types of mills are given in Table 2.2.

2.2. Design of Coarse and Medium Crushers

Jaw crushers. Lumps of the material are crushed between a stationary vertical jaw and a moving inclined jaw hinged onto an axle and powered by an electric motor through a crank. The design of the crusher is shown in Figure 2.1.

Mounted in rigid frame *1* is fixed jaw *2*, a corrugated plate of a wear-resistant material. Moving jaw *5* with detachable corrugated plate *4* is suspended from spindle *6* at an angle to fixed jaw *2*. The working volume between the jaws is restricted by smooth plates *3* installed on both sides.

The moving jaw is swung about spindle *6* by connecting rod *8* seated on main (eccentric) shaft *7*.

The connecting rod is hinged to the moving jaw by means of distance plates *9*. The pull in the moving system of jaw—distance plates—connecting rod and the return movement of the jaw are achieved by pull rod *10* and thrust spring *11*.

The width of the discharge slot is controlled by wedges *12*. Flywheels *13* on the ends of the main shaft ensure uniform

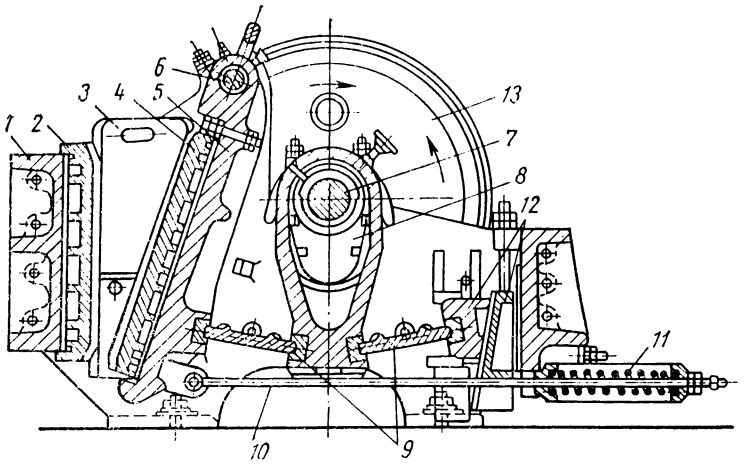


Fig. 2.1. Jaw crusher

1 — frame; *2* — fixed jaw; *3* — smooth plates; *4* — detachable corrugated plate; *5* — moving jaw; *6* — spindle; *7* — shaft; *8* — connecting rod; *9* — distance plates; *10* — pull rod; *11* — thrust spring; *12* — wedges; *13* — flywheels

load of the motor. The output of the jaw crusher is determined from the formula

$$Q = 0.15\mu d_{av} Slbn\gamma, \text{ ton/hour}$$

where μ = loosening coefficient for the comminuted material; it varies from 0.2 to 0.65

d_{av} — average diameter of a piece of comminuted material, cm

S = jaw travel, cm

b — length of discharge slot, cm

n — shaft speed, r.p.m.

γ = density of material, kg/cm^3

The average diameter of the pieces of the comminuted material is calculated from the formula

$$d_{av} = \frac{2e + S}{2}$$

where e = minimum width of the discharge slot, cm.

Hammer crushers. The material in a hammer crusher is comminuted by impacts of hammers hinged to a rotor rotating at a high speed. Each hammer has a stored kinetic energy of

$$E = \frac{mV^2}{2}$$

where V peripheral speed of hammer rotation, m/s
m mass of hammer, kg

The design of a hammer crusher is shown in Fig. 2.2. The split body of the crusher consists of lower part *1* and upper part *2*. The upper part of the body is fitted with feed funnel *3*. Rotor *4* is mounted on a shaft inside the body. Hammers *5* are fixed to the rotor. The internal part of the body is lined with wear-resistant plates *6*. In the lowest part of the body is installed grate *7*. The clearance in the grates determines the granularity of the material. Hammer crushers are generally used for crushing reduced spongy iron, nickel, copper, and tungsten. Their output depends on the properties of the material, the clearance in the grates, the mass, number and shape of the hammers, rotor length, and speed of rotation. The energy consumption per hour of hammer crusher can be determined using the empirical formula:

$$N = 0.1Qi, \text{ kW}$$

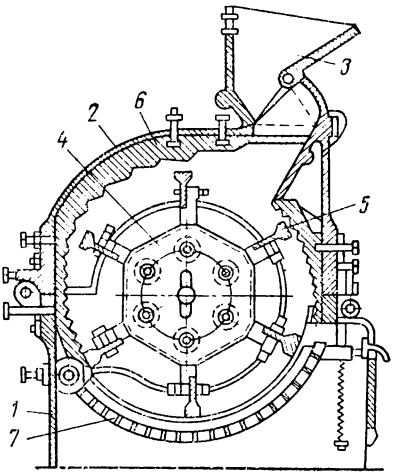


Fig. 2.2. Hammer crusher
1 — lower body; *2* — upper body; *3* — feed funnel; *4* — rotor; *5* — hammers; *6* — lining plates; *7* — grate

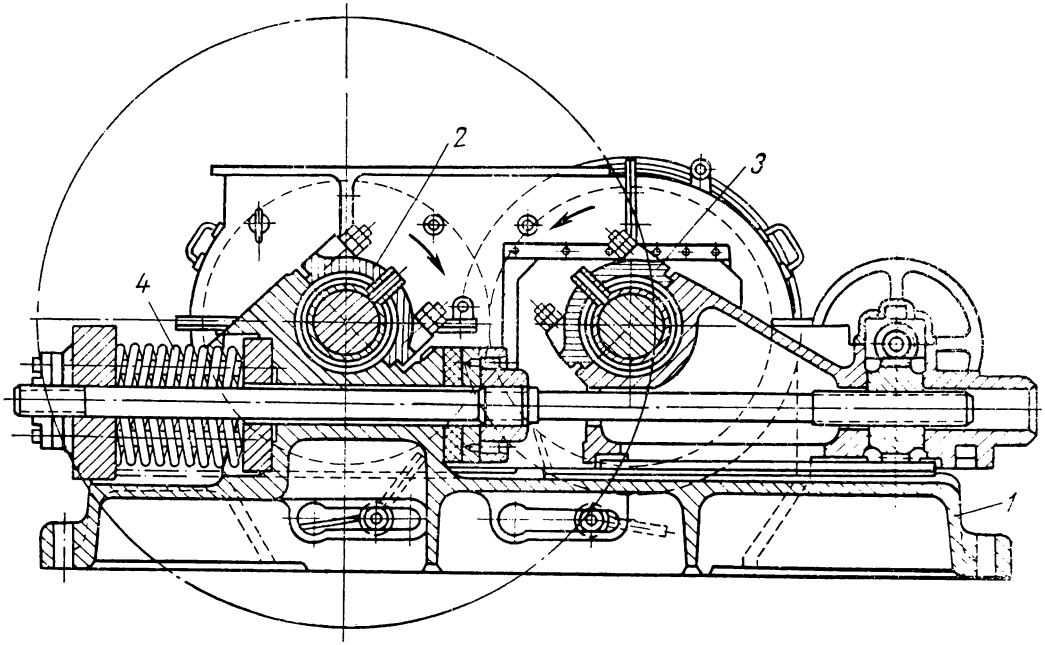


Fig. 2.3. Rolling crusher

1 — bed; *2* — floating bearings; *3* — fixed bearings; *4* — adjustable springs

where Q — output, ton/hour
i — fineness factor

Hammer mills have the same design, as hammer crushers, the sole difference being in the grate clearances.

Rolling crushers (Fig. 2.3) have a comparatively simple design. One roll is mounted in a pair of fixed bearings *3* on bed *1*. The other roll is installed in floating bearings *2* which can travel horizontally and are kept in the required position with respect to bearings *3* with the help of adjustable springs *4*. Each roll has an individual driving pulley. The rolls rotate toward each other, they catch the material and crush it. The rolls may be cylindrical or polyhedral, smooth or corrugated. They may rotate with the same speed or with different speeds. In the latter case the roll crushers, referred to as differential crushers, are used for crushing viscous material. The peripheral speed of the rolls is usually equal to 2.0-4.5 m/s.

The output of roll crushers is calculated from the formula

$$Q = 188.4DZ(l + p)n\rho\mu, \text{ ton/hour}$$

where D — roll diameter, m
Z — roll width, m
l — width of the discharge slot, m
p — average widening of the slot, which depends on the spring stiffness and the strength of the crushed material, m
n — roll speed, r.p.m.
ρ — density of crushed material, kg/m^3
μ — loosening coefficient (0.2-0.3 for hard materials, 0.5-0.6 for wet and tough materials)

2.3. Design of Mills

Ball mills are most popular in industry, and they are very often used in powder metallurgy for making both powders and powder mixtures.

A ball mill (Fig. 2.4) consists of a cylindrical drum partially filled with balls or cylindrical rollers. When the drum rotates, friction against the drum walls entrains the balls to a certain height, from where they freely fall or roll down

and, in so doing, grind the material by impact and attrition.

The efficiency of grinding depends on the operating conditions, on the charge and on the drum dimensions. Investigations show that the optimum diameter of the mill for

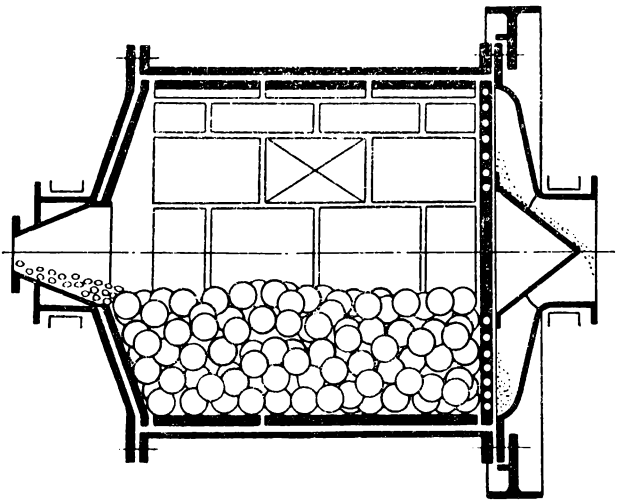


Fig. 2.4. Ball mill with a diaphragm

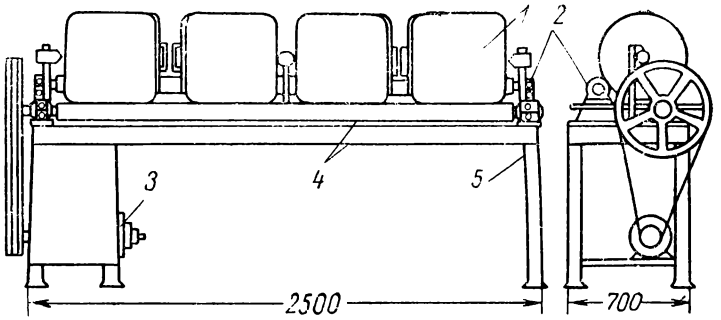
grinding powders is about 250 mm. With greater drum size, the grinding rate does not increase, and with smaller size, the rate decreases.

There are ball mills with continuous and with intermittent discharge.

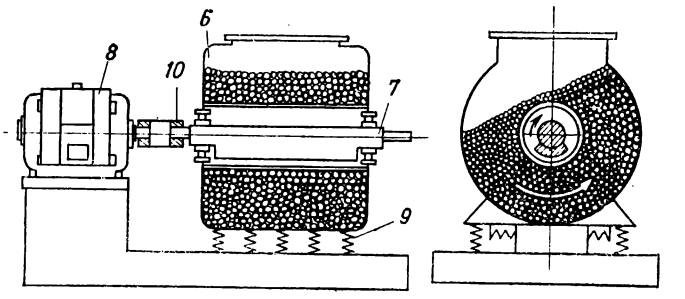
The continuously discharged mills have, near the discharge trunnion, a screen diaphragm with solid radial ribs that divide the space between the diaphragm and the end plate into sector chambers. The comminuted material, passing through the diaphragm apertures, is lifted by the radial ribs to the level of the discharge trunnion and is removed from the mill.

Ball mills with intermittent (central) discharging have no diaphragm. The grinding is carried out for a definite period and then the contents of the mill are discharged.

The roller type of ball mills is shown in Fig. 2.5*a*.



(a)



(b)

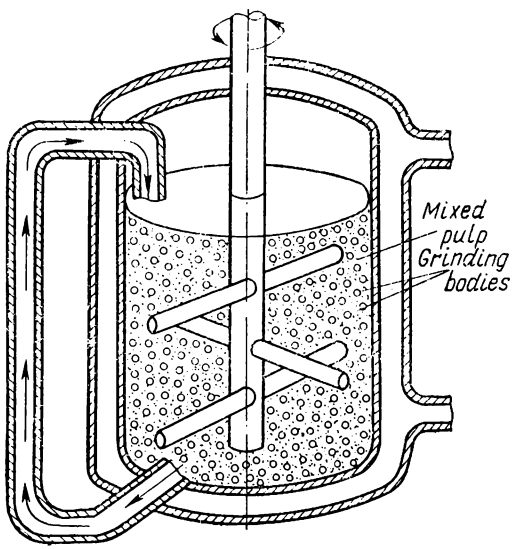


Fig. 2.5. Types of mills

(*a*) roller mill; (*b*) vibrating mill; (*c*) grinding unit; *1* — drums; *2* — bearings; *3* — motor; *4* — rubber rollers; *5* — frame; *6* — casing; *7* — vibrator; *8* — electric motor; *9* — springs; *10* — elastic coupling

Specifications of ball mills with central discharge are given in Table 2.3.

Table 2.3

Characteristics of Ball Mills

Characteristics	Mill types			
	BBM-1	BBM-2	BBM-3	BBM-4
Minimum working volume, m^3	0.9	2.2	4.5	9.0
Drum dimensions, mm:				
inside diameter without lining	900	1200	1500	2100
length	1800	2400	3000	3000
maximum radius of scooping	900	1150	1400	1500
diameter of inlet opening	300	400	400	400
Length of mill without drive, mm	3500	5000	5500	6500
Drum speed, r.p.m.	40	35	30	24
Maximum rating power of electric motor, kW	28	48	95	220
Mass, kg:				
mill without electrical equipment and balls	7000	16,000	20,000	46,500
balls	1900	4900	9700	22,000

The rod mills differ from ball mills in that rods are used for grinding instead of balls. The rod diameter, depending on the mill drum diameter and on the granularity of the discharge material, is in the range of 40 to 100 mm. The mill speed varies from 12 to 30 r.p.m.

Vibrating mills. Ball and rod mills yield powders with particle sizes from 5 to 100 μ.

Finer powders require longer periods of grinding. The tendency to intensify grinding has lead to the designing of vibration mills (Fig. 2.5*b*).

Comminution in vibrating mills is a process in which the mixture to be ground is subjected to vigorous action

of multitude of grinding bodies moving inside the drum in different directions at varying speeds as result of applied vibratory loads.

A vibrating mill unit consists of an electric motor joined by an elastic coupling to the shaft of the drum; the latter is lined inside with rubber and filled to 80 per cent of its volume with the grinding bodies and mixture. After charging, the drum cover is closed. To create the vibrations an eccentric shaft is mounted inside the mill, and the drum itself is joined to the frame by helical springs. Thus, the rotation of the eccentric shaft causes the drum of the vibrating mill not to rotate but only to oscillate.

The vibration frequency is equal to the number of revolutions per minute of the shaft and amounts to 1500 or 3000 oscillations per minute. The amplitude of oscillations is 2 to 3 mm.

The grinding bodies are steel or carbide balls 10 to 20 mm in diameter. Usually the mass of the balls is 8 to 10 times the mass of the ground materials.

The vibrating mills are used for fine and superfine comminution of materials to particle sizes of 60 μ and less.

The most extensively used vibrating mills are those of 50-, 125- and 250-litre capacity.

Vortex mills. Lately vortex mills find ever wider applications in fine and superfine grinding. The vortex mill is diagrammed in Fig. 2.6.

A vortex mill consists of a lined wear-resistant body whose crushing chamber *1* accommodates two propellers *2* running at a speed of up to 3000 r.p.m. Their rotation creates vortices which entrain pieces of metal charged into the mill from bin *3*, knock them against each other and grind them. The ground material, drawn through the mill by fan *6*, settles in chambers *4* and *5*.

The granularity after grinding varies from 50 to 200 μ. When the particles collide they become heated, oxidized and stick together, therefore the mill is cooled with water during the operation. For this purpose the body of the mill is provided with a water jacket. To prevent oxidation of the powder an inert or protective gas is continuously delivered into the crushing chamber.

The grinding unit. The most efficient type of grinding equipment is the grinding unit which comprises a fixed steel drum lined inside with carbide plates (see Fig. 2.5*c*).

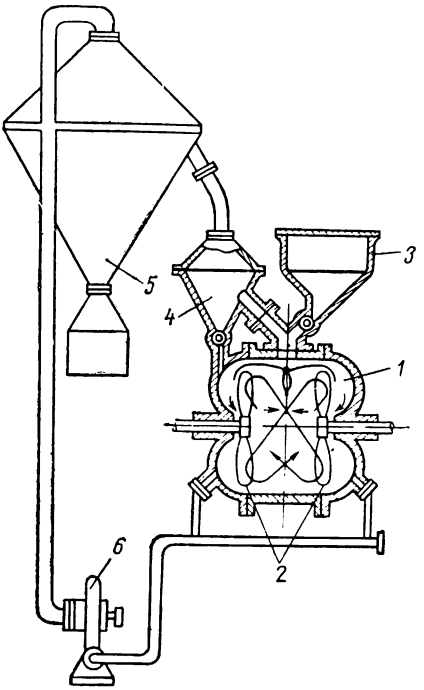


Fig. 2.6. Vortex mill
1 — crushing chamber; *2* — propellers; *3* — bin; *4,5* — discharge chambers; *6* — fan

The grinding bodies are activated by means of paddle-fitted crossarm (stirrer), also carbide-lined. The volume of the unit depends only on the strength of the paddle crossarm, which has to sustain the effect of the balls and mixture.

2.4. The Principal Properties of Powder Materials

Chemical composition of a powder is determined by the contents of the main component, various admixtures, and gases. Physical properties of a powder include particle shape and size, specific surface, and the pycnometric density.

Manufacturing properties include the bulk density of the material, fluidity of the powder, and its compactibility. To make products of the required quality, the powders must meet stringent requirements.

CHEMICAL PROPERTIES

Chemical properties of powders are determined by analyses in analytical laboratories. The powders should be sufficiently pure and contain not less than 98-99 per cent of the main component. The total amount of impurities should not exceed 2 per cent.

The impurities in the powders may have the form of solid solutions or chemical compounds contained in the metal structure, whereas the mechanical contamination occurs in the form of oxides and particles of the crushing and grinding units, products of wear of the grinding bodies and the lining.

The oxides impair the compactibility of the powders and cause a rapid wear of the dies. To reduce the oxide content, the powders are heated to 800-1050°C in a hydrogen atmosphere and are kept at this temperature for some time.

All powders contain a considerable amount of gases. For example, one kilogram of electrolytic-iron powder may contain 8 to 10 litres of gas.

The presence of gas makes compacting more difficult; the intensity of gas liberation during sintering of moulded products may lead to a considerable warpage and even to rupture of the articles. The gas content in powders is determined by heating and fusing the metal in vacuum. This is a very complicated and time-consuming process and it is used only in laboratory research practice.

The chemical properties of the powders include also pyrophoricity, i.e., the capability of igniting spontaneously when exposed to air. Pyrophoricity depends upon the chemical composition of the material, particle size, shape, and character of surface.

Thus, powders of copper, lead, and tungsten are not pyrophoric, but very fine powders of iron and cobalt readily ignite when exposed to air.

Another chemical feature is the toxicity of some powders. For example, when the fine powder of nickel gets into the human body, it causes abrupt morbid changes in the blood. Therefore, before using metal powders, safe operation should be ensured.

PHYSICAL PROPERTIES

The shape of the powder particles depends on the method of its manufacture. If the carbonyl method is used, the powders consist of round (spherical) particles.

When reducing metals from oxides, the powders have a spongy structure. The powder particles produced by grinding in vortex mills have a flaky form. Powders obtained by crushing in ball mills have particle splinter form. Fibrous and petal-form powders are obtained in attrition mills.

The shape of particles greatly influences the manufacturing properties of powders: their bulk, fluidity, compactibility, as well as the strength, density, and other properties. For example, powders with spherical particles have the largest bulk density, but they do not compact well; pieces made of such particles are not strong and crumble easily. Powders with splinter-shaped particles have a better compactibility.

PARTICLE SIZE AND SIZE DISTRIBUTION

The sizes of particles and size distribution are most important properties of a powder.

The dimensions of the particles influence the bulk density, specific pressure in compacting, shrinkage of compacts in sintering, and the mechanical properties of finished articles. Of very great importance is also the size distribution of particles, i.e., the definite relationship between the large and small particles.

The particle sizes in one batch of powder may differ 500 times and more. It is desirable that the mixture to be compacted and sintered have an optimum collection of particles according to size.

There have not yet been given clear recommendations as to the optimum sizes of particles and best relationships between the sizes, as these recommendations depend on many

factors and, first of all, on the designation of the article. The most efficient powder compositions by size are determined experimentally.

Depending on particle size, the powders are classified into ultrafine with particle size less than 0.5 μ; very fine, from 0.5 to 10 μ; fine, from 10 to 40 μ; medium fine, from 40 to 150 μ; and coarse, from 150 to 500 μ.

To determine the percentage of particles of various sizes, sieve or microscopic analysis is made. In the former case, the powder is screened through a set of sieves with square meshes of different sizes. The sieves are installed one above another in a decreasing mesh. A batch of 100 grams of the powder is put onto the top sieve and all the sieves are shaken, usually with the help of some mechanical device, for 15 to 20 minutes. When the sieving is over, the remainders on each sieve and on the tray under the set of sieves are weighed and expressed as the percentage in respect to the total mass of the sample.

The results of the sieve analysis are represented in the form of tables or diagrams. To designate the powder fraction remaining between two adjacent sieves, a special notation is introduced. Thus, if the upper sieve has mesh 0125 and it is followed by sieve mesh 0080, then the powder fraction that has passed through sieve 0125, but remained on sieve 0080 is denoted as 0125 + 0080 (fraction minus 0125 plus 0080).

Table 2.4 shows the characteristics of sieves used in the USSR, the USA and Great Britain.

The sieve analysis is characterized by great simplicity and high efficiency, therefore it is widely used for classification of powder particles more than 40 μ in size. For particles smaller than 40 μ sieve analysis becomes difficult, as it is very difficult to make sieves with less than 40 μ mesh. Recently precision sieves have appeared in the USA, termed 'micromesh' and 'microplate', they widen the range of application of sieve analysis down to 5 μ.

However, these sieves are not being widely used yet and particles of fine powders are measured by microscopic analysis. The method of microscopic analysis consists in preparing a specimen of the powder to be investigated and examining it under a microscope in transmitted or reflected

Table 2.4

Wire Sieves Used in the USSR, the USA and Great Britain

USSR			USA		Gre t Britain	
sieve No.	size of mesh side, mm	wire diameter, mm	sieve No.	size of mesh side, mm	sieve No.	size of mesh side, mm
08	0.800	0.300			—	—
05	0.500	0.220	—	—	—	—
045	0.450	0.180	—	—	—	—
0315	0.315	0.140	—	—	—	—
0250	0.250	0.130	—	—		—
0180	0.180	0.130	—	—		—
0150	0.150	0.120	100	0.147	100	0.152
0125	0.125	0.090	115	0.124	120	0.124
0100	0.100	0.070	150	0.104	150	0.104
0080	0.080	0.055	170	0.089	170	0.089
0063	0.063	0.045	200	0.074	200	0.076
0056	0.056	0.040	250	0.061	240	0.066
0040	0.040	0.030	270	0.053	300	0.053

light. To determine the size of the particle the microscope eyepiece is fitted with a scale. Knowing the scale division, the particles are measured and their percentage in the sample is calculated.

Besides microscopic analysis, the particle sizes of fine powders are measured by the sedimentation method, based upon the difference in the rate of settling of particles of different sizes in liquids. However, the microscopic and sedimentation methods find use only in research work.

THE SPECIFIC SURFACE OF PARTICLES

The specific surface of a powder is the total surface of all the powder particles contained in unit volume or unit mass. The magnitude of the specific surface depends on the shape and size of the particles and may be up to several square metres per gram of powder. The value of the specific surface is determined by the method of adsorption of dyes,

vapours of methyl alcohol, or nitrogen or by measuring gas permeability.

The principal method of measurement of gas permeability is by determination of resistance which the powder offers to a flow of gas.

The powder that is investigated (Fig. 2.7) is placed into cell *14*. Air is exhausted from the system to a vacuum

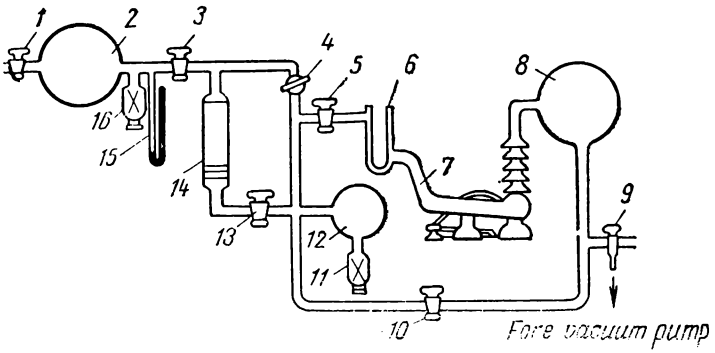


Fig. 2.7. Unit for determining the total specific surface

1, *3*, *4*, *5*, *10*, *13* — two-way valves; *2* — four-litre vessel; *6* — freezing trap; *7* — diffusion pump; *8* — cylinder; *9* — three-way valve; *11*, *16* — pressure-gauge valve; *12* — two-litre vessel; *14* — cell with filter; *15* — mercury vacuum gauge

of $(5 \text{ to } 8) \cdot 10^{-3}$ mm mercury. Then valves *4*, *5* and *10* are closed, valve *3* is opened, and the air passes from vessel *2* at a pressure of 0.1-10 mm mercury into the system and infiltrates through the layer of powder. Simultaneously with opening valve *3*, a stopwatch is started, and the changes in pressure under the specimen in vessel *12* are noted. Using the measurement data, a diagram of change in pressure is plotted against time of infiltration (Fig. 2.8).

From the diagram the time lag L is determined. Then the specific surface S is determined by the formula

$$S = \frac{144}{13} \cdot \frac{\theta}{1-\theta} \cdot \frac{L}{(\Delta X)^2} \sqrt{\frac{2RT}{\pi m}}$$

where m = molecular mass of air
R = universal gas constant

θ powder porosity, a fraction of unity
ΔX height of the powder layer in the cell, cm
T temperature during experiment, K

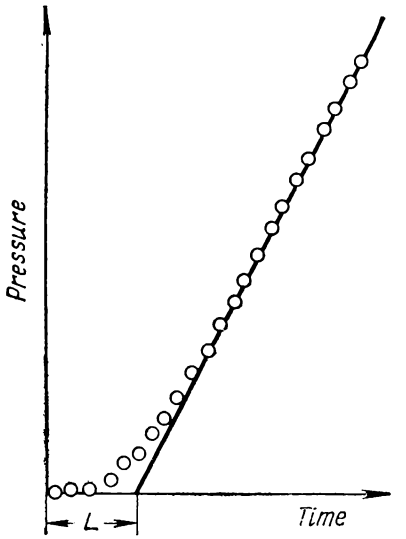


Fig. 2.8. Pressure under the specimen *vs* time

DETERMINATION OF ADSORPTION OF POWDERS

This method is based on the measurement of the amount of methanol vapour adsorbed by the powder. The value of adsorption varies with the conditions of powder production, which makes this method suitable for controlling the conditions in powder manufacture.

PYCNOMETRIC DENSITY

The density of powder particles is, as a rule, less than that of the material of which the powder is made. This is due to the fact that powder particles have internal pores and impurities in the form of oxides. The density of powder particles is determined by an instrument called a pycnometer. The pycnometer is a calibrated vessel of a certain volume (10, 25, 50 millilitre).

Before the pycnometric density is measured, the powder sample and the empty pycnometer are thoroughly dried, then the pycnometer is weighed, filled two-thirds full with the powder and weighed again. After this the remaining volume in the pycnometer is filled with the pycnometric liquid.

The pycnometer with the liquid and powder is weighed for the third time. The pycnometric density is then calculated according to the formula

$$\gamma_p = \frac{F_2 - F_1}{\frac{V - F_3 + F_2}{\gamma_l}}$$

where F_1 mass of pycnometer, g
F_2 mass of pycnometer with powder, g
F_3 mass of pycnometer with liquid, g
V volume of pycnometer, cm^3
γ_l density of pycnometric liquid, g/cm^3

The accuracy of measurement of γ_p is greatly affected by the picnometric liquid. The liquid chosen should thoroughly wet the metals, but not dissolve them. The pycnometric liquid should possess a stable density, minimum values of vapour tension, viscosity, low surface tension, and small size of molecules. The best pycnometric liquid is benzyl alcohol.

MANUFACTURING PROPERTIES OF POWDERS

The most important manufacturing properties are bulk density, fluidity, and compactibility.

The bulk density of the powder γ_b is the mass of unit volume of loose powder. The bulk density is determined with the help of a volumeter (Fig. 2.9).

The powder is loaded into the volumeter through a funnel whose top part is tapered to 60° and the 2-cm long cylindrical stem has an internal diameter of 4 mm. The powder particles pass through a gauze of 0.2-0.3 mm mesh in the funnel and roll down glass shelves into the measuring vessel.

The measuring vessel is topped with some surplus powder which is then reduced to wall level by means of a glass plate. The measuring vessel with the powder is weighed with

an accuracy of 0.01 g. The mass of the powder in the vessel is then determined and the bulk density is calculated according to the formula

$$\gamma_b = \frac{M_2 - M_1}{V}$$

where M_1 = mass of the measuring vessel, g
M_2 = mass of the measuring vessel with the powder, g
V = volume of the measuring vessel, cm^3

The determination of the bulk density is repeated 3 to 4 times and the mean value is accepted. Sometimes for practical purposes it is necessary to know the bulk volume of the

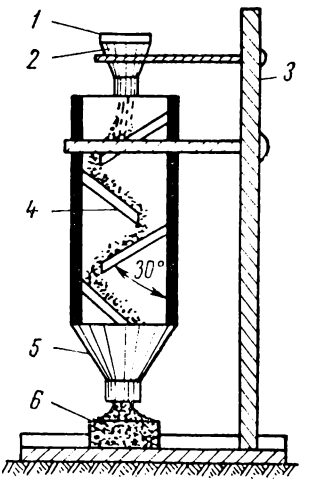


Fig. 2.9. Volumeter
1 — funnel; *2* — gauze; *3* — holder; *4* — glass shelves; *5* — casing; *6* — measuring vessel

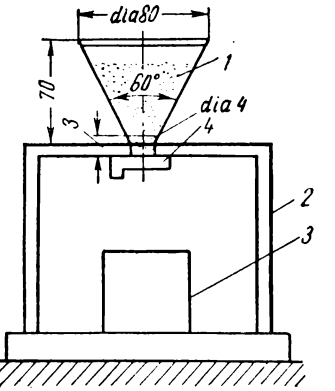


Fig. 2.10. Device for determination of powder fluidity
1 — funnel; *2* — holder; *3* — receiver; *4* — plug

powder, which is denoted by V_b and determined from the expression $V_b = \frac{1}{\gamma_b}$. The bulk mass of the powder characterizes its compactibility. The greater the bulk mass, the better the compactibility of the powder and the less its porosity. Powder porosity characterizes the part of the volume occupied by the pores. The porosity is denoted P

and expressed as a percentage,

$$P = \frac{V_{por}}{V_b} \cdot 100$$

where V_{por} = volume occupied by the pores.

The fluidity of powders characterizes the rate of their passing through an opening of a given diameter. The fluidity is a very important manufacturing property of a powder. The greater is the fluidity, the easier and faster are dies filled with powder, the more uniform is the distribution of density in compacting, and the higher the productive capacity. The fluidity depends on the density of the metal, the sizes and shapes of the particles. Usually, the smaller the particles, the worse their fluidity. If the shapes of the particles are irregular with ragged edges and indents, the fluidity is reduced. Moisture adsorbed on the particle surface greatly hampers the flow of powder.

The fluidity of a powder is determined in an instrument, shown in Fig. 2.10. A sample of powder (50-100 g) is charged into the funnel whose outgoing part has a cylindrical spout with a 4-mm internal diameter.

Before charging the powder, the outlet is closed with a plug. A measuring vessel is placed underneath. To find the fluidity d, the time t required for filling the vessel is measured.

The fluidity of the powder is equal to

$$d = \frac{M}{t}, \text{ kg/s}$$

where M = mass of the powder in the measuring vessel, kg.

A very important manufacturing characteristic is also the compactability of a powder, i.e., its capability to attain the shape and size of the internal space of the die under the effect of external forces.

Compactability can be evaluated in terms of the minimum compacting pressure sufficient to obtain a pellet capable of restoring its shape upon removal from the die. The notion of compactability of a powder includes two conceptions: packability and mouldability.

Packability is determined by plotting a diagram of pellet density against compacting pressure. The mouldability of

a powder is estimated as the ratio of compression strength of the sample to the specific pressure in compacting,

$$K_m = \frac{\sigma_{com}}{P_s}$$

where K_m — mouldability factor

σ_{com} — compression strength, kgf/mm²

P_s — specific pressure in compacting, kgf/mm²

The compactability of powders depends to a great extent on the shape and size of the particles and on the distribution of particle sizes. Fine-grained powders are, as a rule, difficult to compact, but the strength of the moulded articles is higher than that of the articles made of a coarse-grained powder of the same metal.

The powders composed of various-sized particles possess higher bulk mass and ensure the maximum strength of the part. The optimum amounts of coarse and fine particles in a powder are chosen by experiment.

The compactability depends also on the hardness of the powder particles. The harder the powder particles, the higher the required moulding pressure. Therefore, powders of hard metals are annealed before compacting.

CHAPTER III

Production of Tungsten, Cobalt, and Nickel Powders

The previously discussed methods of powder production involved mechanical comminution of the starting material without changing its composition. Below we shall consider the fundamentals of the production of metal powders by physicochemical methods. The essence of these methods is in the chemical effect of special reagents on the starting material. In the process of the reaction the chemical composition of the substance and its state of aggregation are changed.

The following physicochemical methods of making powders are used extensively: reduction of metal oxides by the action of gaseous or solid reducing agents, electrolysis of aqueous solutions or fused medium, and thermal dissociation of carbonyls.

3.1. The Physical and Chemical Processes in Reduction

The method of reduction is most efficient, because the starting materials are metal oxides obtained directly from ores or as waste products of metallurgical processes.

The reduction method is used chiefly to obtain powders of tungsten, molybdenum, copper, nickel, cobalt, and iron. Reduction is the conversion of an oxide or salt into an element or a lower oxide by removal of oxygen (or an acid residue) with the aid of another substance, the reducer, which is more active than the reduced metal.

The reduction reaction may be described by the equation

$$MeO + X \rightleftarrows Me + XO$$

where Me = oxide metal
X = reducer element

For the reaction to proceed successfully, the reducer element must be more active in respect to oxygen than the reduced metal; in other words, the reducer should combine with oxygen more actively.

The reduction reaction is reversible. This means that in the course of the reaction oxides of the reduced metal coexist with those of the reducer and that reoxidation of the previously reduced metal can take place.

To make the reaction proceed only in the direction of reduction and continue to the very end, it is not only necessary to have a reducer with a high affinity to oxygen, but also it is of paramount importance to maintain an appropriate temperature and a definite composition of the atmosphere in the reaction zone and to remove particles of metal from the oxides as soon as the metal is reduced.

The most active reducers are hydrogen, carbon monoxide and carbon black. Metal reduction with hydrogen and carbon monoxide proceeds according to the following reactions:

$$MeO + H_2 \rightleftarrows Me + H_2O$$
$$MeO + CO \rightleftarrows Me + CO_2$$

The reduction with hydrogen is more extensively used than reduction with carbon monoxide because of the difficulty of obtaining pure carbon monoxide.

Carbon black is often used as a reducer, but in this case the reduced metal becomes carbonized, which is not always desirable.

3.2. Reduction of Tungsten Oxides

The starting material for making tungsten powder is tungstic acid anhydride WO_3, a lemon-yellow finely dispersed powder obtained by dehydration of tungstic acid H_2WO_4 or by thermal decomposition of ammonium paratungstate $5(NH_4)_2O \cdot 12WO_3 \cdot 11H_2O$.

Tungstic acid is dehydrated at 700-750°C:

$$H_2WO_4 \rightarrow WO_3 + H_2O$$

Ammonium para-tungstate is decomposed at a temperature exceeding 250°C:

$$5(NH_4)_2O \cdot 12WO_3 \cdot 11H_2O \rightarrow 12WO_3 + 10NH_3 + 16H_2O$$

Tungstic acid anhydride (tungsten trioxide) should contain 99.90 to 99.95 per cent WO_3. This anhydride is the highest oxide of tungsten. There are also other oxides of tungsten, differing from each other in colour. The composition and properties of tungsten oxides are given in Table 3.1.

Table 3.1

Composition and Properties of Tungsten Oxides

Tungsten oxide	Chemical formula	Density, g/cm³	Melting point, °C	Combination heat, kcal/mole
Yellow	WO_3	7.2-7.4	1470	202.8
Blue	$WO_{2.90}$ $WO_{2.80}$	7.1-7.2	—	—
Violet	$WO_{2.72}$ $WO_{2.70}$	7.7-8.0	—	—
Brown	WO_2	10.9-11.1	1270	134.0

The complete reaction of tungsten reduction with hydrogen can be expressed by equation: $WO_3 + 3H_2 = W + 3H_2O$. However, the presence of intermediate oxides makes the reaction more complex, consisting of several stages:

$$WO_3 + H_2 \rightarrow WO_{2.90} + H_2O$$
$$WO_{2.90} + H_2 \rightarrow WO_{2.72} + H_2O$$
$$WO_{2.72} + H_2 \rightarrow WO_2 + H_2O$$
$$WO_2 + H_2 \rightarrow W + H_2O$$

In the course of reduction with hydrogen, oxygen is removed from the tungstic acid anhydride; water vapours, lower tungsten oxides (at the intermediate stages of reduction) and tungsten (at the final stage) are formed.

The water vapours formed reoxidize the reduced powders, and thus the reduction process consists of a number of reduction-oxidation (redox) processes taking place continuously.

Under the influence of water vapours, a volatile oxide WO_2 is formed. The WO_2 vapours precipitate on the surface of tungsten particles and, being re-reduced, add to the size of the tungsten particles. The rate of the reduction process depends on the concentration of water vapours which, in turn, depends on such factors as temperature, rate of material travel through the furnace, humidity and quantity of hydrogen, etc.

In the course of the reaction, the state of chemical equilibrium may take place, i.e., conditions when the reduction stops. With an increase in temperature, as a rule, the equilibrium shifts in the direction of reduction. The reduction reactions can take place when the water vapour content in the gaseous mixture is considerable.

The equilibrium conditions for the reactions of tungsten reduction with hydrogen are given in Table 3.2.

Table 3.2

Equilibrium Compositions of the Gaseous Phase in Tungsten Reduction with Hydrogen

Reaction	Temperature, °C	Composition of gaseous phase, per cent	
		H_2O	H_2
$WO_3 \rightarrow WO_{2.90}$	630	74	26
	750	89	11
$WO_{2.90} \rightarrow WO_{2.72}$	630	57	43
	750	83	17
$WO_{2.72} \rightarrow WO_2$	630	45	55
	750	50	50
$WO_2 \rightarrow W$	600	9	91
	750	17	83
	843	27	73
	881	30	70
	950	36	64

Reduction of tungstic acid anhydride with hydrogen is, as a rule, carried out directly at the plants where the sintered metal carbides are manufactured. Use is made of electric furnaces with one, two or four metal or ceramic muffles and with two or three zones of heating or in electric furnaces with one or several (up to 11) metal tubes.

For reduction, tungstic acid anhydride WO_3 is charged into trays. The trays are placed into the furnace muffles and gradually transported along the muffle by a drive from the charging end to the discharging end of the furnace.

Hydrogen, which should be sufficiently dry and clean, is continuously passed through the furnace. The moisture content in hydrogen should not exceed 2 g/m^3 and the oxygen content should not be over 0.4 per cent by volume.

The reduction conditions are chosen so as to ensure the required granularity of the powder. For fine-grained powders the reduction temperature should be maintained within the range of 600 to 700°C. Medium-grained powders are produced at reduction temperatures of 800 to 900°C. Coarse-grained powders require a reduction temperature equal to 1200°C. The reduction period lasts 2 to 3 hours.

Grain size distribution in tungsten powders is given in Table 3.3.

Table 3.3

Grain Size in Tungsten Powders

Powder	Percentage of tungsten grains measured in μ							
	0-1	1-2	3-4	4-8	8-12	12-20	20-40	40-80
Fine-grained	95	3	2	—	—	—	—	—
Medium-grained	76	16	8	—	—	—	—	—
Coarse-grained	40	11	15	4.5	2	6	2.5	1

The reduction is carried out, as a rule, in two stages in different furnaces. During the first stage the tungstic acid anhydride is reduced to brown oxide WO_2, during the 2nd stage the latter is reduced to metal. The division of the process is economical as it increases the furnace output.

With a single-stage reduction, as the trays move, the amount of material (oxide and powder) decreases because of

oxygen loss. Therefore, at the end of the furnace the moving trays are only partially loaded.

In the case of two-stage reduction, the trays are delivered for the second stage fully loaded with brown tungsten oxide. The single-stage reduction method is used chiefly for making coarse-grained tungsten powder.

The conditions of reduction of tungstic acid anhydride for making medium-grained tungsten powder are as follows:

Mass of WO_3 loaded in one tray, kg . .	2.1-2.2
Reduction temperature, °C:	
first zone	740±20
second zone	850±20
third zone	880±20
Periodicity of tray movement through tray length, minutes	10-12
Hydrogen supply to furnace, m^3/hour . . .	3.7-4.5

After reduction the tungsten powder is sieved on a vibrating sieve with a mesh of 0.25 to 0.18 mm.

The sieved powder is collected into batches weighing 400 to 800 kg and delivered for preparing the charge for carbonizing. The tungsten powder should contain not more than 0.25 per cent of oxygen. The pulverized metallic tungsten obtained by reducing the oxides is a greyish-black powder whose colour varies depending on its granularity. Fine-grained powders are black and coarse-grained ones are grey. The size of the powder grains depends on the grain size of the starting anhydride and on the reduction conditions; it can vary from fractions of a micron to hundreds of microns.

The principal factors that control the granularity of tungsten powder are the changes in the reduction temperatures and the composition of the gaseous atmosphere in the reaction space. It has been established that the following conditions are required for making coarse-grained powders:

(a) high temperature of reduction;
(b) rapid raise of temperature along the tube furnace length;
(c) high rate of material travel along the furnace;
(d) deep layer of tungstic acid anhydride in the trays;
(e) slow flow of hydrogen;
(f) increased humidity of hydrogen.

To obtain a fine-grained powder, it is necessary to use a fine-grained anhydride, to reduce it at a comparatively low temperature, to use dry hydrogen passed at a high speed

through the furnace, and to gradually increase temperature along the furnace length while the trays are moving.

Tungstic acid anhydride may also be reduced with carbon. In this case the reduction involves the participation of the gaseous phase. The reducer is carbon monoxide which gradually removes oxygen from tungsten oxides. Since tungsten has several oxides, the reaction of WO_3 reduction to metallic tungsten comprises several stages as in the case of reduction with hydrogen. This process can be summarized by the following equations:

$$2CO \rightleftarrows CO_2 + C$$

$$WO_3 + 3CO = W + 3CO_2$$

The reduction of tungstic acid anhydride with carbon proceeds at higher temperatures than the reduction with hydrogen. This is stipulated by the temperature of CO formation.

When reducing WO_3 with carbon the granularity of tungsten is more difficult to control.

The reduction of WO_3 with carbon is usually carried out at temperatures of 1400-2000°C in electric furnaces with graphite tubes.

3.3. Reduction of Cobalt and Nickel Oxides

Cobalt, nickel, and copper have a low affinity to oxygen, therefore their oxides are easy to reduce.

Cobalt powder is made from cobaltic oxide Co_3O_4 by reducing it with hydrogen H_2 in a four-muffle direct-heating electric furnace or in an electric furnace with two metal muffles. The length of the heating zone of a furnace is equal to 2000-3000 mm. The power of the furnace is 30 to 50 kW. The reduction process takes place according to the reaction:

$$Co_3O_4 + 4H_2 = 3Co + 4H_2O$$

The trays are filled (without packing) with cobalt oxide and charged into the furnace with hydrogen continuously passed through. The moisture content in hydrogen should not exceed 0.4 g/m³. The reduction temperature is maintained at 530 to 550°C. The periodicity of tray shift varies from 7 to 12 minutes, depending on the tray design and furnace dimensions.

After reduction, cobalt powder is sieved on a vibrating sieve with 0.1-0.6 mm mesh.

The oxygen content in cobalt powder should be not more than 0.7 per cent and the bulk density of the powder should not exceed 0.75 g/cm^3.

The chemical composition of the powder should be (per cent): for grade КП1, not less than 99.4 Co, not more than 0.4 Ni, 0.06 C, 0.10 O_2, 0.05 Cu, 0.03 Si, 0.25 Fe, 0.2 moisture; for grade КП2, not less than 97.5 Co, not more than 0.5 Ni, 0.08 C, 0.10 O_2, 0.08 Cu, 0.05 Si, 0.2 moisture.

The nickel powder is made from nickelic oxide NiO. The raw materials for obtaining NiO are nickel carbonates and oxalates. Nickelic oxide is reduced with hydrogen, ammonia, and converted gas at a temperature of 700 to 750°C for 1 to 2 hours.

3.4. Equipment and Instruments Used in Reduction of Oxides

Oxides of tungsten, cobalt, nickel, and copper are reduced in muffle furnaces or in tube furnaces. Oxides are charged into special trays which are loaded into the furnace. The trays are made of stainless steel. Their size is 280 × 280 × 10 mm.

Most often used are the four-muffle reduction furnaces. The specifications of a reduction furnace are as follows:

Permissible temperature, °C	1000
Number of heating zones	3
Length of the heated portion, mm	3200
Muffle cross section, mm	300 × 70
Muffle length, mm	5100
Rated output of the furnace, kW	120
Hydrogen flow rate per muffle, m^3/hour	30-40
Furnace dimensions, mm:	
length	7650
width	2530
height	2145
Material of muffles	heat-resisting steel
Heaters	coils of 6 mm nichrome wire
Temperature control	automatic
Tray conveyance in the working volume of the furnace	by pneumatically-driven mechanical pusher

The working conditions of the furnace, the temperature, and the hydrogen flow rate are controlled by the following instruments and devices: electronic potentiometers; chromel-alumel thermocouples; ammeters; voltmeters; devices for thermocouple switching; a gasometer; and a rotameter.

Reduction tube furnaces are provided with gas or electric heating. Figs 3.1 and 3.2 show two types of rotary-tube furnaces.

The principal unit of the furnace is the tube made of stainless steel. The tube rests on roller supports. The working part of the tube is heated by nichrome heaters. The front and rear heads of the furnace are connected to the tube by means of stuffing boxes. The furnace may be inclined 10° to the horizontal. The tube rotates at a speed of 80 r.p.m. The furnace is charged from an air-tight screw conveyor running at speeds from 0 to 6 r.p.m. A water cooling system is provided.

An advanced furnace with a better mixing of materials (Fig. 3.2) is divided into several zones. The inclination of the furnace is controlled in the range of 2 to 4°.

The furnace is lined inside with ultralight-weight brick. The longitudinal grooves made in four sides of the lining accommodate nichrome heating coils of the controlled dome and bottom heaters. The furnace is charged with an air-tight screw conveyor. The maximum daily output of the furnace is two tons of powder.

Another and better type of rotary-tube furnace that has been developed in the USSR has the following features:

(a) the working volume of an annular cross section is located between two concentric tubes; one end of the internal tube is fixed to the external tube;

(b) in the working volume is installed a headpiece in the form of T-shaped racks, staggered on the internal and external tubes; this headpiece ensures a uniform distribution of the material being reduced;

(c) the internal tube is used for preheating the hydrogen to be delivered into the working volume.

Rotary-tube furnaces are easily incorporated into transfer lines since the charging and discharging operations are carried out continuously.

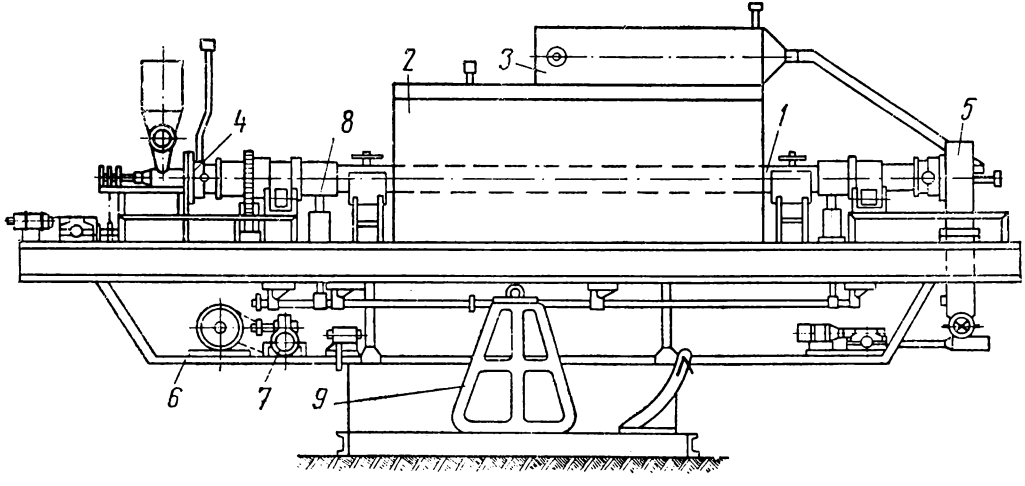


Fig. 3.1. Rotary-tube furnace

1 — tube; *2* — furnace heater; *3* — gas preheater; *4* — charging head; *5* — discharging head; *6* — furnace girder; *7* — drive for tube rotation; *8* — impact device; *9* — frame

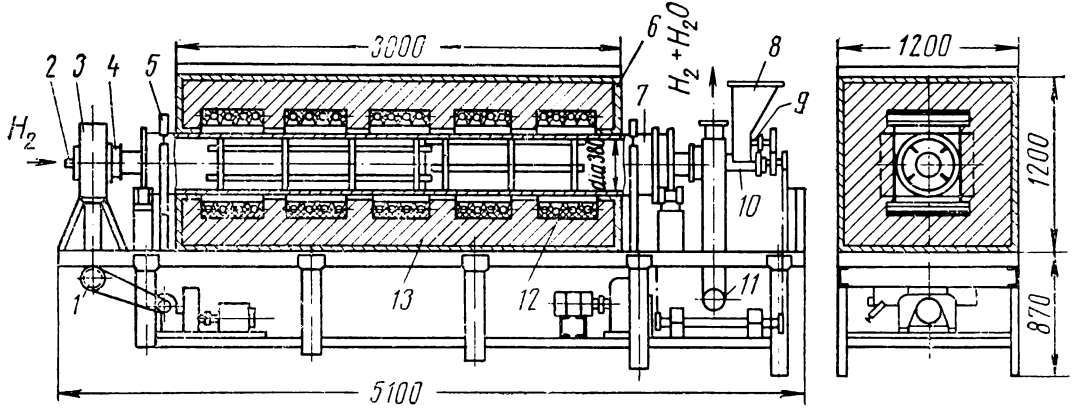


Fig. 3.2. Rotary-tube furnace

1 — discharging screw conveyor with drive; *2* — hydrogen preheater; *3* — discharging head; *4* — stuffing box; *5* — impact device (shaker); *6* — body; *7* — rotary tube; *8* — charging bin; *9* — loosener; *10* — charging drive; *11* — screw conveyor for discharging dust; *12* — heater; *13* — brick lining

CHAPTER IV

Production of Refractory Metal Carbides

4.1. Properties of Carbides

Carbides of refractory metals have superior physical, mechanical and chemical properties. They are distinguished by their very great hardness and strength, high melting point, and high corrosion-resistance, especially to mineral acids.

Chemical corrosion-resistance data of carbides to mineral acids are given in Table 4.1.

Table 4.1

Chemical Corrosion-Resistance of Carbides

Carbide	Acid				
	HCl	H_2SO_4	HNO_3	HF + HNO_3	HCl + H_2SO_4
TiC	ND	ND	—	D	—
ZrC	ND	D		D	
VC	ND	ND	D	—	—
NbC	ND	D	ND	D	ND
TaC	ND	ND	ND	D	ND
Cr_3C_2	ND	—	D	—	D
Mo_2C	ND	ND	ND	ND	—
WC	ND	—	—	—	—

Note. ND — does not dissolve; D — dissolves.

At room temperature the carbides are negligibly oxidized by the air oxygen. With an increase in temperature, the resistance of carbides to oxidation in air decreases:

Carbide	TiC	ZrC	TaC	NbC	VC	Mo_2C	WC
Temperature when active oxidation begins, °C	1100 to 1400	1100 to 1400	1100 to 1400	1100 to 1400	800 to 1100	500 to 800	500 to 800

Chlorine and other halogens begin to react with carbides at temperatures of 500 to 700°C. Nevertheless carbides are easily decomposed when fused with alkalis or treated with hot alkali solutions.

4.2. Methods of Carbide Production

Carbides can be produced by the interaction of carbon and its compounds with metals or their compounds. The following methods of making carbides are practised:

(1) production of carbides in a cast form;

(2) carbonization of metal powders (or oxides) with solid carbon;

(3) carbonization of metal powders (or oxides) with gases containing carbon (often in the presence of solid carbon);

(4) precipitation from the gaseous phase (build-up method);

(5) chemical separation of the carbide phase or carbonic ferroalloys or melts (dissolving method);

(6) electrolysis of melts of the relevant salts.

The first three methods are the principal industrial methods used.

Cast carbides are produced by fusing metals with carbon and this is possible only in an electric or high-frequency furnace as the temperature of forming and fusing of carbides lies in the range of 2500 to 4000°C. This causes technical difficulties, and therefore the method of production of cast carbides has a limited application.

The production of carbides by carbonization of metal powders or metal oxides with solid carbon has the most extensive use in the industry for making carbides of tungsten, titanium, molybdenum, tantalum, vanadium and other carbides, used in the production of sintered carbides.

Powders of pure metals or their oxides are the starting materials used for this method. Carbon is introduced into the mixture in the form of a fine powder of sugar charcoal or carbon black. The mixture of the metal (or oxide) with carbon is thoroughly mixed in ball mills by dry or wet methods. When mixing the metal with solid carbon, 5 to 10 per cent of carbon over and above the theoretical content is added because of the residual oxygen present in metal powders, and to compensate the carbon partially burnt out in the furnace.

When using mixtures of metal oxides with carbon, the carbonizing effect of the carbon oxide formed and the protective gas used are taken into account. For this reaction, usually 80 to 90 per cent of carbon is sufficient, which corresponds to the equation

$$MeO + 2C = MeC + CO$$

Carbonization is carried out in one or several stages in an electric, or (more seldom) in gas furnaces. Besides muffle continuous-action furnaces, use is made of carbon tubular resistance furnaces, continuous furnaces with molybdenum electric heaters and vertical three-phase kryptol furnaces, as well as high-frequency intermittent action furnaces with graphite crucibles.

Hydrogen, carbon monoxide, methane, and mixtures of these gases are used as the protective gas. When producing carbides of tungsten and molybdenum, producer gas or dissociated ammonia may be used as protective gases.

The carbonization reaction, when monocarbides are formed, takes place according to the following equations:

(1) in the solid phase

$$Me + C \rightleftarrows MeC$$

$$MeO + 2C \rightleftarrows MeC + CO$$

(2) in the gaseous phase

$$Me + 2CO \rightleftarrows MeC + CO_2$$

$$MeO + 3CO \rightleftarrows MeC + 2CO_2$$

The temperature created during the reaction of carbonization of metals with solid carbon, depending on the form of carbide, lies in the range of 1200 to 2200°C. Table 4.2

Table 4.2

Temperatures of Carbonizing with Solid Carbon for Various Mixtures

Carbides	Composition of mixture	Temperature of reaction, °C
TiC	TiO_2 + carbon black; $Ti(TiH_2)$ + carbon black; TiO_2 + carbon black + chlorine derivatives of hydrocarbon	1700 to 2100
VC	$V_2O_5(V_2O_3)$ + carbon black; V + carbon black	1100 to 1200
TaC	Ta_2O_5 + carbon black; Ta + carbon black	1300 to 1500
Mo_2C	MoO_3 + carbon black; Mo + carbon black	1200 to 1400 1100 to 1300
WC	WO_3 + carbon black; W + carbon black + hydrocarbon	1400 to 2000 1200 to 1400

gives the temperatures of reactions for obtaining the more important carbides from metals or oxides when carbonizing with solid carbon in the presence of a hydrocarbon.

Carbides of molybdenum, tungsten and tantalum are best produced by carbonizing metal powders with sooty carbon at a temperature of 1200 to 1600°C.

At room temperature, tungsten forms two stable carbides, W_2C and WC. When carbonizing in the solid phase, the tungsten monocarbide WC is mainly formed; when carbonizing in the melt, W_2C is formed. Sintered metal carbides contain only tungsten monocarbide.

Titanium carbide is made from a mixture consisting of titanium dioxide (as pure as possible) and gas black at a temperature of 1700 to 2100 C.

The production of carbides by carbonization of metals or their oxides with gases containing carbon. It has been previously shown that when carbide-formation takes place in the solid phase, carbonization occurs also by means of the gaseous phase. In connection with this it is possible to obtain carbides by carbonization in the gaseous phase only. For this purpose the metal and a hydrocarbon are used, and as a result of the reaction, a metal carbide and hydrogen are produced. Gas carbonization of metals takes place at higher temperatures.

The method of carbonization of oxides with carbon-containing gases is seldom used.

4.3. Tungsten Carbide

Tungsten monocarbide, WC, is used for the production of carbides; it is made by carbonizing metal tungsten powder with carbon black in a stream of hydrogen in tubular or muffle resistance furnaces, as well as in large muffle furnaces heated with coke or gas.

Tungsten monocarbide is formed as the result of the chemical interaction of the metal with carbon.

This reaction is expressed by the equation

$$W + C = WC$$

The process of carbonization of tungsten is accomplished in a gaseous atmosphere containing carbon. The carbonizing temperature for tungsten is in the range of 1300 to 2000°C.

Carbonization in a gaseous atmosphere takes place according to the following reactions:

$$C + CO_2 = 2CO$$

$$2CO + W = WC + CO_2$$

As the result of the reactions, a layer of tungsten carbide is formed on the tungsten particles which gradually extends inwards. The duration of the reaction depends on the particle size of the starting tungsten powder and on the temperature of the process. The stoichiometric content of carbon in the

tungsten carbide is equal to 6.12 per cent (by mass). Any change in the carbon content leads to a drop in the strength of the alloy. It has been found, that the strength of the alloy decreases more considerably with a deficiency of carbon, than with an excess of carbon. The content of combined carbon in the carbide depends on the temperature of the process (Fig. 4.1).

When furnaces with a graphite tube are used, the process may be carried out in an atmosphere of CO + N_2, which

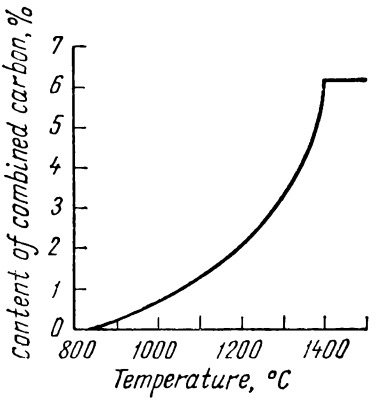


Fig. 4.1. Dependence of carbon content in tungsten carbide on the carbonization temperature

is formed when air penetrates into the furnace. The temperature of carbonizing is changed according to the granularity of the starting tungsten powder. For the finer powders a temperature of 1300 to 1350°C may be used. For coarse-grained powders the temperature should be increased to 2000°C.

The granularity of the carbide powder depends on the granularity of the tungsten powder. The coarser the tungsten powder, the larger the carbide grains. It has been noticed, that the size of carbide grains made of coarse-grained tungsten powders is slightly smaller than the initial grains of tungsten. This is explained by the fact that during the carbonizing process the coarse grains of tungsten are split up by inner stresses due to diffusion of carbon and changes in the crystal lattice. The grains of fine-grained powders of tungsten are not subjected to comminution when carbonized.

The grain size of tungsten carbide may be changed by subjecting carbides to wet grinding in mills.

Tungsten carbide is a grey metal powder which slowly reacts with acids. It is resistant to chlorine up to a temperature of 400°C and begins to react with it only at 600 to 800°C. Fluorine already combines with WC in the cold and with a flash. Tungsten monocarbide is slowly oxidized to WO_3 when heated in air or in oxygen. The physical properties of tungsten monocarbide are as follows:

Density, g/cm³:	
calculated	15.77
by experiment	15.5 to 15.7
Modulus of elasticity, kgf/mm²	73100
Poisson's ratio	0.20
Microhardness, kgf/mm²	1730
Elongation, per cent	0
Ultimate strength, kgf/mm²:	
compressive	300
bending	52-56
tensile	35
Melting point, °K	2870
Heat conduction, cal cm·s·degree	0.07
Thermal coefficient of linear expansion, 10^{-6} K	4.4

4.4. Production of Tungsten Carbide

The starting products for making tungsten carbide are tungsten powder and lamp black. The content of impurities in a starting tungsten powder suitable for manufacture of carbides should be total not more than 0.2 per cent ($\geqslant 0.05$ per cent Fe, $\geqslant 0.05$ per cent $SiO_2 + Al_2O_3$, $\leqslant 0.05$ per cent of bases and other impurities). Carbon black should contain not less than 99 per cent C, less than 0.1 per cent of ash, 0.5 per cent of volatiles and less than 0.2 per cent of moisture.

The amount of carbon is calculated so that the tungsten carbide, WC, contains 5.9 to 6.15 per cent of pure carbon. Before mixing, the tungsten powder is sieved through a bronze gauze with a 0.25-mm mesh and charged into a ball mill or mixer for obtaining a uniform mixture. The mixing schedule is given in Table 4.3.

The mixture produced (filled into a tray or in the form of a briquet) is charged into the carbonizing furnace.

Table 4.3

Preparation of Mixture for Carbonization of Tungsten

Mixing unit	Grinding bodies (steel balls)		Charge of mixture components, kg		Speed (r.p.m.) of unit	Duration of mixing, h
	dia, mm	mass, kg	W			
Ball mill, 500-litres	15 to 35	150 to 160	350 to 370	Calculated	35 to 40	3
Mixing drum, 1.5-m³	15 to 35	600	680	Ditto	31	4

Table 4.4

Conditions of Carbonization of Tungsten

Carbonization unit	Temperature of carbonizing, °C	Mass in tray, kg	Periodicity of tray travel per length of tray (330 mm), minutes	Hydrogen supply, m³/h
Two-zone electric furnace with graphite muffle	1360	11.5 to 12.5	10	Not more than 1.0
	1430			
Two-zone electric furnace with ceramic muffle	1380			3 to 4
	1450			
Electric furnace with graphite tube	1450	6 to 7	10	Not more than 1.0
	1500			
	1750			
	2000			

Carbonizing is accomplished in a two-zone electric furnace with a graphite or ceramic muffle, or in an electric furnace with a graphite tube.

The conditions for carbonizing are given in Table 4.4. Loading or unloading of trays is usually done by hand. The trays are pushed through with a mechanical pusher.

The tungsten carbide produced is ground in ball mills. Below is given the schedule for tungsten carbide grinding in a 500-litre ball mill.

Grinding bodies (steel balls):	
diameter, mm	15 to 50
mass, kg	175 to 180
Mass of WC charge, kg	360 to 400
Mill speed, r.p.m.	35 to 40
Duration of grinding, hr	2

After grinding, the carbide is sifted in a powered sieve through a silk or capron gauze with a 0.18-0.15-mm mesh.

Table 4.5

Specifications of Electric Furnaces Used for Carbonization of Tungsten

Data	Type of furnace	
	with a ceramic muffle	with muffle of graphite blocks
Permissible temperature, °C	1500	1500
Number of heating zones	2	2
Length of heated portion, mm	2000	2 × 1050
Muffle material	Ceramics	Graphite
Muffle cross section, mm	250 × 160	250 × 130
Heaters	Molybdenum rods	
Installed power, kW	40	41
Loading and unloading of trays	Automatic	
Pushing of trays	Mechanized	
Overall dimensions of furnace, mm:		
length	6970	7210
width	1870	1660
height	1730	1634

According to specifications the tungsten carbide should contain not more than 0.1 per cent of free carbon. The specifications of electric furnaces used for carbonizing tungsten are given in Table 4.5.

4.5. Production of Titanium Carbide

Titanium carbide is produced by annealing a mixture of titanium oxide and carbon black in a hydrogen atmosphere or in vacuum at high temperatures (2000 to 2200°C). Titanium carbide is formed according to the overall reaction

$$TiO_2 + 3C \rightarrow TiC + 2CO$$

Carbonization proceeds through the three following stages:

$$2TiO_2 + C \rightarrow Ti_2O_3 + CO$$
$$Ti_2O_3 + C \rightarrow 2TiO + CO$$
$$TiO + 2C \rightarrow TiC + CO$$

These stages show how complicated the formation of titanium carbide is and that strict adherence to the technological process is required at all stages so that the reaction proceeds to the very end with stage-by-stage conversion of titanium oxide into titanium carbide.

Titanium carbide is light grey in colour and is chemically very resistant to the action of hydrochloric and sulphuric acids. It readily dissolves in nitric and hydrofluoric acids, and in aqua regia also; when fused with peroxides and alkalis it readily decomposes.

Titanium carbide is easily chlorinated, fluorine reacts with TiC in the cold, and the other halides react when they are heated to 400-700°C. Powdered titanium carbide oxidizes at 500 to 600°C, compact titanium carbide does not oxidize till 800°C. The product of oxidation of titanium carbide is TiO_2.

The stoichiometric content of carbon in titanium carbide, in accordance with the formula TiC, is equal to 20 per cent. Experimentally, by carbonizing in vacuum it was possible to obtain a titanium carbide with a maximum content of combined carbon of 19.2 to 19.3 per cent. This carbide is best wetted by cobalt. TiC has the properties of a semiconductor.

4.6. Production of Titanium-Tungsten Carbide

The starting material for the production of titanium-tungsten carbide is titanium oxide TiO_2, lamp black, and a tungsten powder (or tungsten carbide). These components in the dry state are mixed in a 1.5-m^3 ball mill, filled with balls 13 to 30 or 50 to 70 mm in diameter. The duration of mixing is approximately equal to 8 to 10 hours. The mass of the components in the mixture is determined by calculation based on the reaction equation for carbonization.

Carbonization is carried out in electric resistance furnaces with a graphite tube in a hydrogen atmosphere with continuous pushing of the trays. The carbonizing temperature is in the range of 2000 to 2300°C.

The produced carbide is crushed and then ground in ball mills of a capacity of 200 to 400 litres. The period of grinding depends on the required granularity of the carbide and can vary from 3 to 20 hours. After grinding, the carbide is sifted through a sieve with a 0.25-mm mesh and made up into batches up to 500 kg.

Titanium-tungsten carbide should contain not less than 9.45 per cent of combined carbon and 23 to 25 per cent of titanium. The free carbon content should not be more than 0.3 per cent; iron impurities should not exceed 0.3 per cent; the adsorption of metal vapours should be within 0.02-0.07 mg/g.

CHAPTER V

Preparation of Mixtures

5.1. Mixing Methods

Sintered metal hard alloys are comprised of carbides and cementing or bonding metals. The constituents of mixtures for industrial hard alloys that are employed are tungsten carbide, titanium-tungsten carbide, carbides with additions of tantalum carbide, niobium carbide, vanadium carbide, etc.; and the bonding metal is cobalt taken in amounts corresponding to the composition of the alloy and its grade.

The preparation of mixtures is one of the principal operations of the technological process. The quality of an alloy to be manufactured largely depends on how carefully this operation has been carried into effect. Deficiencies in preparing the mixture cannot be corrected in the course of the subsequent operations, such as pressing and sintering.

A number of methods for mixing carbides with a cementing metal are known, namely: depositing a cobalt salt on the tungsten carbide powder, depositing a bonding metal from solutions by means of zinc dust, the mechanical intermixing of constituents in the dry state or in the presence of a liquid.

In the first method, a cobalt salt solution is poured onto the carbide powder, for instance, cobalt carbonate salt $CoCO_3 \cdot mCo\,(OH)_2 \cdot nH_2O$ or cobalt oxalate CoC_2OH_4 followed by evaporating the solution while mixing it. As a result, there is formed a mixture of powdered carbide with a solid salt which is roasted in a hydrogen stream. When being roasted, the cobalt salt decomposes, and the evolved carbon dioxide and hydrocarbons escape therefrom. This gives rise to the formation of a mixture of carbide with metal cobalt.

The second mixing method is based on the reaction of substituting metallic zinc for metal cobalt in a solution

of the complex cobalt-ammonia chloride $[Co(NH_3)_6]Cl_3$.

This mixing method consists in preparing an ammonia solution of cobalt chloride by mixing the cobalt chloride solution with ammonia water. Thereafter, powders of carbide and metallic zinc are added to the ammonia solution of cobalt chloride. On being vigorously mixed, the cobalt solution reacts with metallic zinc, as a result of which the finest cobalt particles are deposited on the powdered carbide which is in suspension.

The following reactions occur under these conditions:

$$Zn + 4NH_3 + 2H_2O \rightleftarrows [Zn(NH_3)_4](OH)_2 + H_2$$

$$[Zn(NH_3)_4](OH)_2 + 2NH_4Cl \rightleftarrows [Zn(NH_3)_4]Cl_2 + 2NH_3 + 2H_2O$$

$$2[Co(NH_3)_6]Cl_3 + 3H_2 \rightleftarrows 2Co + 6NH_4Cl + 6NH_3$$

After the reaction is completed, the solution is allowed to settle in a reactor and then drained. The deposit is repeatedly washed by a weak solution of ammonium chloride and then in a suction filter with alcohol until water is fully removed therefrom. The resulting mixture is dried in steam drying cabinets, and is then subjected to grinding.

According to the third mixing method, separately prepared powders of carbides and cementing metal are intermixed either in ball mills or in special grinding apparatus in the dry or wet state.

A modification of this method, which has recently been proposed, involves a technique of rubbing cobalt (from the lining and grinding bodies made of pure metallic cobalt) on carbide particles.

Each of the aforementioned mixing methods has its advantages and drawbacks. The advantages of the first two methods are: very uniform distribution of cobalt among carbide particles and the high productive capacity of the process.

The main disadvantages of these methods are as follows:

1. Decarbonization of carbide when firing mixtures, because of partial reduction of oxides by the carbide carbon, which interferes with adjusting the alloy composition to carbon.

2. Pollution of the mixture of carbide and cobalt with zinc admixtures.

3. Toxicity of the manufacturing process due to ammonia.
4. The necessity for auxiliary equipment.
5. Inconvenience resulting from the inclusion of purely chemical processes in the powder-metallurgy technological process.

The mechanical intermixing of powders has the following advantages:

1. Obtaining a uniform charge of carbide with cobalt (especially when grinding in a liquid medium).
2. Possibility of using starting powders of carbides having any grain size desired.
3. Possibility of controlling the grain size of the carbide constituent of alloys.
4. Absence of impurities in the prepared mixture.

The disadvantages of this mixing method are as follows:

1. Insufficient uniformity of the charge when mixing the powders in the dry state.
2. Long duration of the grinding process.
3. Rapid wear of the grinding bodies and the mill lining.
4. The large amount of work required by the manufacturing process.

The disadvantage of the method of rubbing cobalt on the carbide particles from the balls and lining is that it is impossible to accurately determine the rubbing time required for obtaining the desired mixture composition. For the same mixture composition, the rubbing time will be different on account of the different degrees of carbide powder dispersion (which affects the abrasive properties of the material being ground, the surface of the lining and grinding bodies, i.e., their different roughness), as well as the size of these bodies.

Mechanical mixing of powders is now extensively used in the industry.

The manufacturing process of preparing mixtures by mechanical mixing of the constituents consists of the following operations: weighing the constituents, charging them into a mill, grinding, and discharging the mixture from the mill. When mixing in a liquid, after discharging the mixture, the latter is subjected to drying in drying cabinets or in distillers. The mixing schedules are selected mainly by trial.

5.2. Processes Occurring when Grinding a Mixture

After short-time dry grinding (about 2 hours) the starting carbide powders consist of grains or grain conglomerates, the size of which varies within a fairly considerable range from 0.5 μ to 1 mm.

The grains of the cementing metal (cobalt) differ from the carbide grains in shape and size. The cobalt powder

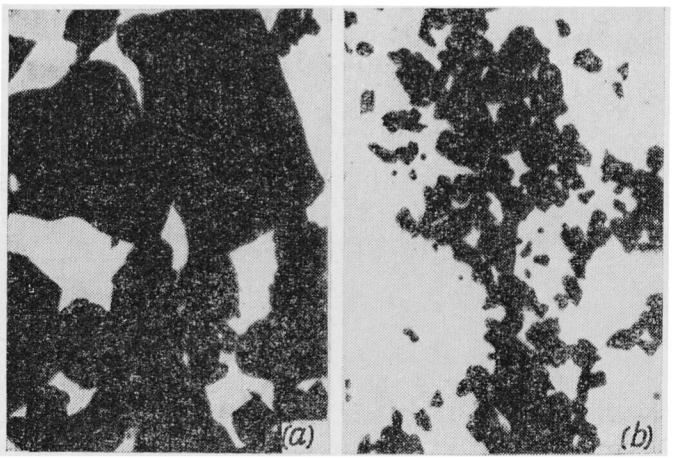


Fig. 5.1. Tungsten carbide powder, photographed by means of an electron microscope (10,000 ×)
a) prior to grinding; (*b*) after wet grinding during 48 hours

consists of readily disintegrating conglomerates with the size of separate grains ranging from 0.3 to 2 μ. When preparing mixtures, the conglomerates and separate grains of tungsten carbide and cobalt disintegrate, and cobalt is distributed in the common matrix of carbide grains until a homogeneous mixture is obtained within microvolumes. The greatest variation in the granularity of tungsten carbide and cobalt occurs in the first stage of the grinding process. It has been established that when tungsten carbide is ground during 24 hours about 85 per cent of the matrix consists of grains up to 0.5 μ in size. Besides, there are also separate grains 3

to 4 μ in size the amount of which constitutes about 1 per cent. In the course of the following four days, the granularity of tungsten carbide gradually becomes finer; and on the fifth day, the content of grains up to 0.5 μ in size already amounts to 95 per cent; about 5 per cent of the grains are up to 1 μ in size.

In the course of the grinding operation, the cobalt particles markedly disintegrate, too. It has been established that

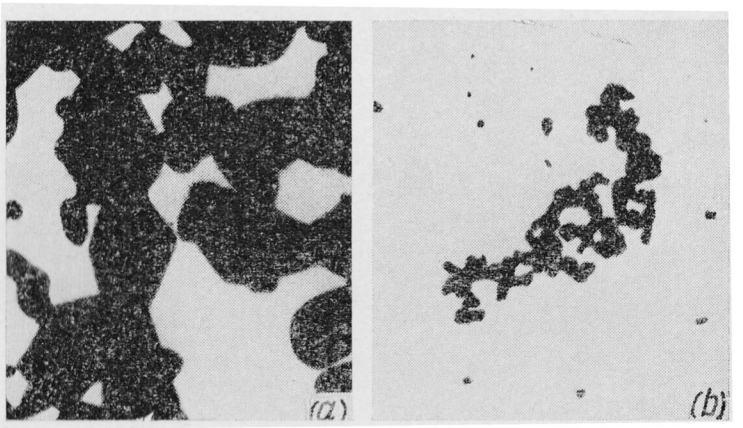


Fig. 5.2. Cobalt powder, photographed by means of an electron microscope (10,000×)
(*a*) prior to grinding; (*b*) after wet grinding during 48 hours

after wet grinding during 48 hours the cobalt grain size varied from 1-2 to 0.1 μ and finer. Figs 5.1 and 5.2 show the tungsten carbide and cobalt powders prior to and after grinding.

The additional disintegration plays a fairly important role in the grinding process for obtaining a homogeneous mixture; for without this operation it would be practically impossible to achieve good intermixing of different powders. The high disintegration of cobalt is conducive to its uniform distribution among the carbide particles. The apparent uniformity of the mixture is achieved during a fairly short period of time, say 2 to 4 hours. This can easily be confirmed

by the results of chemical analysis for cobalt in samples taken from various portions of the mixture being prepared. In this case, the chemical analysis for cobalt will produce fairly similar data.

When sintering pieces briquetted from such mixtures, however, their structure will be non-uniform, and the mechanical properties will not reach the required level, because of the fact that cobalt can be distributed fairly uniformly within the carbide powder volume, but very non-uniformly among the carbide grains. That is why in each specific case, the grinding schedule for a mixture of any grade is established experimentally, simultaneously evaluating the properties of the alloy produced from this mixture. For this purpose, the most extensively used method of taking a 'liquid' sample consists in that the sample is taken off directly from a mill, dried, and mixed with a plasticizing agent. This mixture is made use of to prepare the test pieces which are required for testing the mechanical properties and structure. The analysis data are employed for estimating the suitability of the grinding schedule for preparing the mixture.

5.3. Dry and Wet Grinding Procedures

Powder mixtures are prepared by using two grinding procedures: wet and dry.

Formerly, dry grinding was applied; but this method has been substituted by wet grinding as being more efficient. Dry grinding is effected in an air medium. When grinding in the dry state, even prolonged grinding is incapable of producing the required uniformity of a mixture. In the mill and in the powders being ground there is always present air which separates the particles, keeping them from sticking closely to each other.

The mixture powders are spread throughout the entire volume of the mill, and do not participate in the general process of grinding and mixing. Part of them adheres to the walls of the mill drum and to the grinding bodies, which prevents them from participating in the mixing process. This results in non-uniformity of the alloys produced from dry-ground mixtures. Alloys made of these mixtures

usually have agglomerations of cobalt phase areas and large carbide grains, and are also characterized by a high porosity.

In contrast to dry grinding, wet grinding is carried out in a liquid. For this purpose ethyl alcohol, acetone, and petrol are employed. The liquid to be used in grinding should:

(1) not react chemically with the powders being ground;

(2) have a low boiling point, in order to be easily removed when being dried;

(3) be non-toxic;

(4) be readily available.

The above-mentioned requirements are best met by ethyl alcohol. Water may be used instead of alcohol, but this will necessitate either vacuum drying of the mixture or its reduction in a hydrogen stream; for under ordinary drying conditions the mixture is likely to be oxidized.

The presence of a liquid medium is conducive to better distribution of the metal particles among the carbide particles. In wet grinding, the powders do not spread widely. The pulverized powder particles remain in the liquid, and are continuously ground and intermixed by the grinding bodies. The dispersion of particles facilitates grinding. When crushing conglomerates and powder grains, the capillary forces in the cracks and crevices formed set up a high pressure which contributes to disintegrating the particles.

The wet grinding procedure is especially important in the case of production of alloys with a low cobalt content, where a very small proportion of the bonding metal will have to be distributed in the carbide matrix.

It has been shown that dense, low-cobalt alloys can only be produced by prolonged wet grinding of carbide together with cobalt. Thanks to the aforementioned reasons, wet grinding is conducive to good intermixing of powders, and enables alloys of a better quality to be produced from mixtures prepared in this way.

5.4. Purpose of Grinding Bodies. Their Motion in Grinding Units

Particles are ground, pulverized and intermixed owing to the motion of grinding bodies. In a ball mill, where balls are mainly employed as the grinding bodies, their motion

depends on the number of drum revolutions per minute. The drum rotation speed, at which the grinding bodies rotate together with the drum and are pressed to its wall due to the centrifugal force, is called critical. The critical rotation speed is determined by the formula

$$N_{cr} = \frac{42.4}{\sqrt{D}}$$

where D = drum diameter, m
N_{cr} = drum rotation speed, r.p.m.
42.4 = empirical coefficient

In practice, the drum is rotated at considerably slower rotation speeds than the critical ones. The grinding bodies (balls) act on the material being ground in three different ways: through impact, attrition and by vibration.

1. **Impact produced by the drum rotating at a speed equal to 75 per cent of the critical value.** In this case, the balls rise to some height together with the drum walls, and then fall down. The material is ground by the impact of the falling balls.

2. **Attrition produced by the drum rotating at a speed which does not exceed 60 per cent of the critical value.** In this case, the balls may move in the drum in two different ways:

(a) the balls rise together with the drum wall to a certain height and then fall down along the inclined plane formed by the ball surface. This type of motion of the balls is called rolling over, and is accomplished by the roll-over schedule. In this case, the material is pulverized due to its being ground between the balls;

(b) all the balls rise together with the drum wall at a relatively small height, and then slide down. Such a type of ball motion in a mill is accomplished by a sliding schedule. In this case, the material is pulverized due to its being ground between the surface of the balls and the drum wall.

A grinding schedule based on impact of the grinding bodies on the material being pulverized is generally applied to large-size material with the piece size over 1 mm.

In the production of hard alloys, the most suitable schedules are those based on attrition of the bodies being ground, while the most preferable type of attrition is the roll-over schedule, in which the balls continuously rub against the material being pulverized and all the balls participate in grinding. The motion of the balls in different schedules is diagrammatically represented in Fig. 5.3.

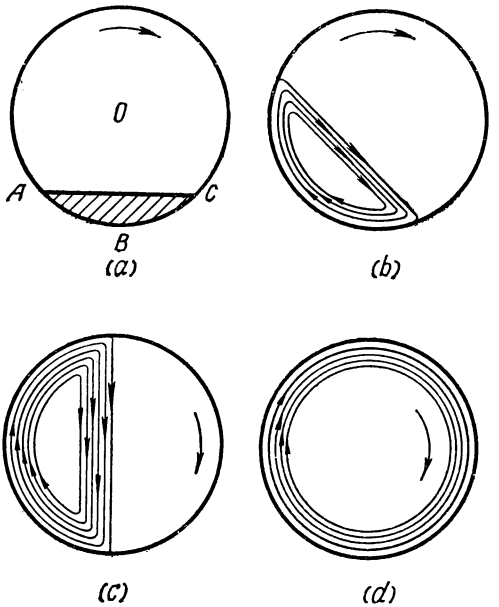


Fig. 5.3. Schematic drawing showing the motion of balls in a mill (*a*) sliding schedule; (*b*) roll-over schedule; (*c*) free-falling schedule; (*d*) motion of balls at the critical rotation speed

In addition to the drum rotation speed, the roll-over schedule depends on the number of balls charged. If the number of balls is large, they are likely to roll over; a smaller number of balls will slide. The roll-over schedule will be achieved, provided that the inclination angle of the surface of the grinding bodies mass is greater than their angle of repose.

In the sliding schedule, the amplitude of oscillations (degree of swinging of the balls mass) depends on the mill's rotation speed. At a fast rotation speed, the surface inclination angle of the swinging mass of balls may sometimes exceed the angle of repose, and part of the balls may roll down so that the ball mill produces a characteristic intermittent noise.

Comparison of the grinding rate attainable with different grinding schedules has shown that the roll-over schedule (under otherwise equal conditions) provides a higher grinding rate than the sliding schedule.

As has been mentioned above, for grinding mixtures, besides ball mills, special-purpose grinding units may be used; these are stationary cylindrical vessels filled almost up to their top with balls. In these units the motion of the balls is effected by rotation of a blade mixer located in the vessel's central part.

This unit functions due to rubbing of the balls against the material being ground owing to the rotation of the balls about their axis. The intensity of rubbing of the balls in this unit is much greater than in the ball mill, because of the fact that in this case all the balls simultaneously participate in the grinding process, whereas in the ball mill, part of the balls (which do not roll over) remains stationary for some time and does not participate in the grinding. That is why the grinding units of such a type have a greater capacity as compared with the ball mills, and, probably, they will be extensively used in the future for grinding mixtures.

3. **Vibration** mills may also be employed for grinding mixtures. Recently, the application of vibration grinding has been steadily growing wherever fine grinding of material is required. The operation of the vibration mill is based on the vigorous and highly frequent action on the mixture being ground of a large number of grinding bodies moving in different directions at alternating speeds.

Vibration grinding may be both intermittent and continuous. The application of vibration grinding is explained by the high output of this method and the possibility of obtaining very fine fractions of ground material.

5.5. Types of Grinding Bodies. Their Dimensions and Composition

Hard-alloy balls or hard-alloy plates, mainly rectangular in shape, may be employed as grinding bodies. The plates wear down non-uniformly when grinding. Moreover, sharp angles and edges may be chipped off and the resulting particles may get into a mixture and contaminate it. All this renders plates unsuitable for grinding a mixture. At the present time, for grinding mixtures in the hard-alloy production, most extensively used are hard-alloy balls that uniformly wear down in the grinding process. On being worn out, the balls grow smaller in size, and they are withdrawn from the mill and replaced by new ones as they reach the minimum diameter specified by technical requirements. It is recommended that the new balls be added prior to charging a new mixture batch when the total loss of the balls' mass, caused by the preceding batch, does not exceed 1.5 per cent, and also when replacing worn-out balls in a quantity approximately equal to 10 per cent of the total amount of balls.

It is desirable to add into the mill balls corresponding to the maximum diameter within the specified range of the sizes of the balls of a given group.

A set of balls of various sizes is generally employed in the grinding process. This assures the best conditions for pulverizing a mixture.

The balls are manufactured in accordance with the generally accepted technological process for producing hard-alloy ware. The composition of the hard alloy is selected, taking into account the specific conditions under which the grinding bodies must work. Since the balls work under conditions of attrition, it would be the most expedient practice to manufacture them of medium-grain WC-Co alloys containing about 4 to 6 per cent of cobalt, as well as of fine-grained alloys of the same composition. Balls which are manufactured of the alloys of the aforementioned grades may be used for grinding tungsten-cobalt and titanium-tungsten-cobalt mixtures. Prior to using the balls for grinding a mixture, they should be rolled over in order to remove their surface defects.

5.6. Effect of the Grinding Degree on the Physicomechanical Properties of Alloys

There is a direct correlation between the grinding schedules of mixtures and the mechanical properties of the alloys produced from them. It is well known that by varying the grinding schedule parameters it is possible to control the granularity of a mixture and, consequently, the granularity of the carbide constituents of an alloy, thus influencing the alloy properties.

When manufacturing WC-Co alloys with different sizes of the carbide grains, a distinct relation between the alloy strength and grain size was established. The bending strength of grade BK6 alloy with a grain size ranging from 1 to 3 μ, was 20 to 25 kgf/mm^2 greater than that of an alloy of the same composition but with a grain size ranging from 0.5 to 2 μ. In fine-grained alloys prepared by vigorously grinding coarse-grained carbide powders, this correlation is not observed. In this case, the fine-grained alloys have the same and sometimes a higher bending strength than medium-grained alloys. Consequently, a reduction in the alloy grain size due to an increase in the intensity and duration of the grinding operation does not bring about a decrease in the bending strength, whereas a reduction in the grain size of alloys as a result of grain refinement of the starting carbide usually causes a decrease in the alloy strength.

Table 5.1 sets forth data illustrating the effect of the rate and duration of grinding tungsten carbide and cobalt on the bending strength of an alloy. The same data were observed when grinding mixtures having a different relation between the grinding bodies and mixture. The higher the grinding rate of the mixture, the greater the strength of alloys prepared therefrom, and vice versa.

In addition to the grinding schedule, the mechanical properties are materially influenced by varying the duration of grinding of the separate components of an alloy, especially a multi-component one. Thus, for example, for producing a coarse-grained alloy, cobalt is first ground, followed by grinding the tungsten carbide for a fairly short time. As a result, there is obtained an alloy with a high bending strength.

Table 5.1

Effect of the Rate and Duration of Grinding on the Coercive Force and Static Strength of an Alloy

Duration of grinding, hours	Ball size, mm					
	5		7		10	
	coercive force, oersted	bending strength, kgf/mm²	coercive force, oersted	bending strength, kgf/mm²	coercive force, oersted	bending strength, kgf/mm²
Sintering temperature, 1390°C; duration, 30 min						
6	148	146	148	145	146	134
12	168	147	160	142	155	125
24	180	155	178	146	171	151
48	210	155	200	157	183	145
96	235	160	220	152	195	135
Sintering temperature, 1430°C; duration, 90 min						
6	141	145	142	152	139	156
12	153	157	150	155	144	150
24	165	157	160	147	152	150
48	167	156	161	166	156	154
96	151	165	154	170	152	158

Table 5.2

Dependence of Porosity on the Duration of Grinding of Starting Mixtures

Duration of grinding, hours	Density, g/cm³	Coercive force, oersted	Number of pores on a microsection area 32 mm² in size, μ		Volume of pores*
			< 16	> 16	
3	14.87	150	2070	140	1.2
6	14.92	162	1640	—	0.55
12	14.90	175	840	—	0.17
24	14.93	202	26	—	0.009
48	14.97	245	10	2	0.004
96	15.02	248	10	1	0.003

* In relation to the dense part of 32-mm² microsection.

To obtain the required granularity of carbide phases when grinding grade T15K6 mixture, different times for grinding the components are also required. The presence of a fine-grained WC-phase in an alloy increases its stability, whereas the presence of a coarse-grained titanium phase gives the required strength. Hence, differing the granularity of the components of an alloy makes it possible to obtain the required combination of strength and wear resistance.

The grinding conditions materially influence the porosity of an alloy produced. Table 5.2 gives data showing the dependence of the alloy porosity on the grinding duration. From these data, it is evident that the alloy porosity decreases as the grinding duration increases.

5.7. Effect of Various Factors on the Grinding Rate

The grinding apparatus output is rather low in wet grinding of hard-alloy mixtures. It is a very important problem to step up the productive capacity of wet grinding mills. For this purpose, the effect of various factors on the grinding rate will have to be elucidated.

DIMENSIONS OF THE GRINDING BODIES

When preparing hard-alloy mixtures, hard-alloy balls of various diameters are employed: 15 to 18 mm, for grinding coarse-grained mixtures; 8 to 12 mm, for grinding medium-grained mixtures; and 3 to 8 mm, for grinding fine-grained mixtures.

The grinding efficiency is estimated according to the change in the granularity of the constituents of a mixture during a certain period of time, and according to the degree of the mixture uniformity which is attained in the same period of time.

The grinding efficiency increases as the ball size grows smaller, which is shown by the change in the coercive force characterizing the grain size of the WC-phase.

The extent of cobalt agglomerations is the least when grinding a mixture with the use of small-size balls. The rate of grinding is approximately inversely proportional to the ball diameter.

CORRELATION BETWEEN THE NUMBER OF BALLS AND THE AMOUNT OF A MIXTURE BEING GROUND

The grinding rate is markedly influenced by the relation between the number of balls and the amount of a mixture being ground. The grinding rate is doubled when the amount of the mixture charged into the mill is reduced to one half of the charge. However, it should not be believed that increasing the relation between the number of balls and the amount of the mixture being ground presents great possibilities for speeding up the grinding process. This is explained by the fact that a marked reduction in the amount of the charged mixture would result in obtaining a great number of small batches which, in turn, would involve additional losses and labour required for recharging the mills. The most adequate balls-to-mixture ratio is about 2.5. When preparing fine-grained and extremely fine-grained mixtures this ratio increases up to 7.

CHARGE OF GRINDING BODIES

The grinding schedule depends on the charge of grinding bodies. The mill should be charged with grinding bodies so that it operates according to a roll-over schedule which provides for attaining the highest grinding rate. The conditions required for achieving a roll-over schedule have been set forth above.

DURATION OF GRINDING

The grinding duration directly affects the intensity of grinding; the longer the grinding time, the higher the degree of pulverization of the mixture.

The grinding time is established experimentally depending on the requirements to be met by the grain size of the carbide phases and the physicomechanical properties of the alloy produced.

ROTATION SPEED OF MILL

The rate of grinding hard-alloy mixtures increases with the rotation speed of the mill. It is, however, necessary to maintain a roll-over schedule of the grinding bodies in the mill, which is assured by a drum rotation speed equalling about 60 per cent of the critical speed.

The increase in the grinding efficiency with an increase in the mill rotation speed is explained by the fact that a greater number of displacements of the balls occur in a given period of time. The rotation speed of the mill is generally within the range of 30 to 36 r.p.m. A further increase in the rotation speed is undesirable, as it does not result in an increase in the grinding efficiency. This is apparently connected with the fact that a part of the grinding bodies is torn off from the main mass and is entrained by the flow of the liquid, thus not participating in the grinding process.

Consequently, the rotation speed of the mill should not exceed the speed at which the balls begin to drop freely.

AMOUNT OF LIQUID

The amount of liquid used, or the solid-to-liquid ratio, plays an important role when establishing the grinding efficiency.

The frequency at which the particles get between the balls increases as the amount of liquid used decreases. The reverse effect is observed when the amount of liquid is increased, i.e., the concentration of the solid particles is decreased. An undue reduction in the amount of the liquid used, however, may bring about an increase in the suspension viscosity, which results in a decrease in the kinetic energy of the balls; this, in turn, will cause a drop in the grinding efficiency. In industrial conditions, there is generally adopted the practice of adding about 400 to 500 ml of alcohol per kilogram of the mixture being ground.

5.8. Ways of Increasing the Rate of Mixture Grinding

The developed techniques of stepping up the grinding rate allow varying the process of manufacturing alloys, especially fine-grained alloys, with a view to improving

their quality. Thus, for instance, intensive grinding enables manufacturing fine-grained alloys of relatively coarse-grained tungsten carbide powders. In this case, a small grain size in an alloy is attained owing to the vigorous crushing of carbide grains in the grinding process, and to the use of a relatively low sintering temperature, preventing rapid grain growth. Such alloys are characterized by low porosity (of the order of 0.1 per cent), uniform distribution of the cementing phase, and fairly high mechanical properties, especially as regards the bending strength (not less than 140 kgf/mm^2 for an alloy containing 6 per cent of Co).

The grinding efficiency of mixtures can be enhanced by determining the grinding rate for each grade of alloy, taking into account all the factors on which it depends.

Recently more advanced and promising grinding techniques are being employed, that make it possible to considerably reduce the time necessary for pulverizing and intermixing the powdered constituents, such as vibration grinding and ultrasonic crushing. The efficiency of vibration grinding can be fairly well demonstrated by the following example: the same values of coercive force of the grade BK6 alloy are attained by grinding in a vibration mill for 24 hours and in a ball mill for 48 hours.

The application of ultrasonic crushing enables the grinding efficiency to be further increased.

At the present time attempts are being made to apply this method to the manufacture of hard-alloy mixtures. This method may prove to be the most efficient technique of pulverizing and intermixing the constituents of a mixture.

One of the most difficult problems consists in producing mixtures of a constant composition having a small deviation of grain sizes.

The solution of this problem is complicated by the fact that different degrees of attrition of the grinding bodies result in various grinding rates of the mixture. That is why the set of the grinding bodies must be strictly controlled both as to their mass and size, in order to obviate considerable variations in the dispersity of a mixture being ground.

5.9. Calculation of Charges for Preparing Mixtures

When preparing mixtures of various grades, the amount of the components to be charged will have to be first calculated.

Since the mixtures are prepared for tungsten-cobalt and titanium-tungsten-cobalt alloys, the charge can be two- and three-component. It is easier to calculate the two-component charge consisting of tungsten carbide and cobalt.

CALCULATION OF THE CHARGE FOR A TWO-COMPONENT MIXTURE

Prior to calculation, the amount of the mixture to be prepared will have to be specified; this is defined by the manufacturing instructions for the alloy of the given grade. Let us assume that the mass of a batch of grade BK6 mixture equals 200 kg.

According to the designation BKn of the tungsten-cobalt alloy grade, it is known that n denotes the amount of cobalt in per cent in the given grade of the alloy. Thus, for example, in grade BK6 alloy, the average content of cobalt amounts to 6 per cent.

Let us further determine the amount of cobalt which should be charged into the mill in order to obtain 200 kg of the mixture:

$$\frac{200 \times 6}{100} = 12 \text{ kg}$$

Since the mixtures for WC-Co alloys are composed of tungsten carbide and cobalt, we must determine the amount of tungsten carbide, which will be equal to:

$$200 \text{ kg} - 12 \text{ kg} = 188 \text{ kg}$$

Consequently, to prepare 200 kg of grade BK6 mixture, 12 kg Co and 188 kg WC must be charged into the mill.

This calculation procedure may be represented as follows:

$$\frac{A \times n}{100} = K$$

$$A - K = B$$

wherein A = amount of the mixture being prepared, kg
n = content of cobalt, per cent
K = amount of cobalt in the charge, kg
B = amount of tungsten carbide, kg

CALCULATION OF THE CHARGE FOR A THREE-COMPONENT MIXTURE

TiC-WC-Co alloys are composed of a complex titanium-tungsten carbide, tungsten carbide, and cobalt. The tungsten carbide is added to the mixture for diluting the titanium-tungsten carbide, so that the content of titanium in the mixture will conform to the existing standards.

The complex carbide contains titanium within the range of 22 to 24 per cent, whereas the content of titanium in titanium-tungsten mixtures is considerably lower. That is why tungsten carbide is added to the mixture, in order to make the titanium content in the mixture conform to the existing standards.

EXAMPLE OF CALCULATING THE CHARGE FOR THE GRADE T5K10 MIXTURE

Let us assume that 200 kg of grade T5K10 mixture should be charged into the mill. Let us further determine the amount of each component of the mixture. The numbers in the grade designation of the alloy show that the cobalt content amounts to about 10 per cent, and that of titanium to about 5 per cent.

Determine the mass of cobalt, which should be charged into the mill in order to obtain 200 kg of the mixture:

$$\frac{200 \times 10}{100} = 20 \text{ kg}$$

Further determine the amount of the complex titanium-tungsten carbide, provided it contains 24 per cent Ti:

$$\frac{200 \times 5 \times 100}{24 \times 100} = 41.66 \text{ kg}$$

The remainder of the mixture should consist of tungsten carbide:

$$200 \text{ kg} - (20 + 41.66) = 138.34 \text{ kg}$$

Hence, to prepare 200 kg of grade T5K10 mixture, a charge composed of 20 kg of cobalt, 41.66 kg of the complex titanium-tungsten carbide, and 138.66 kg of tungsten carbide, is required.

In the general form this calculation procedure may be represented as follows:

$$\frac{A \times n}{100} = K$$

$$\frac{A \times p}{m} = T\,;\quad A - (K + T) = B$$

wherein A = quantity of the mixture being prepared, kg
n = content of cobalt in the alloy of the given grade, per cent
K = amount of cobalt in the charge, kg
p = content of titanium in the mixture of the given grade, per cent
m = content of titanium in the titanium-tungsten carbide, per cent
T = amount of the complex titanium-tungsten carbide in the charge, kg
B = amount of tungsten carbide in the charge, kg

In order to check the calculation thus carried out, let us compare the results obtained with the contents of cobalt, carbon (total), and titanium specified in technical standards for the chemical composition of the mixture of the given composition. If they conform to the standards, the calculation has been carried out properly.

CHECKING THE CALCULATION OF THE CHARGE FOR THE GRADE T5K10 MIXTURE

When calculating the charge for grade T5K10 mixture, the charge was found to comprise the following components: 20 kg of cobalt, 41.66 kg of the complex titanium-tungsten carbide and 138.34 kg of tungsten carbide.

Let us determine the content of cobalt in the mixture, per cent;

$$\frac{20 \times 100}{200} = 10$$

Then determine the content of titanium in the mixture. To prepare the mixture required, 41.66 kg of the complex titanium-tungsten carbide were added. The carbide contained about 24 per cent titanium.

Consequently, the mass of titanium in this carbide will be equal to

$$\frac{41.66 \times 24}{100} = 9.998 \text{ kg (that is about 10 kg)}$$

Determine the percentage of titanium in the mixture:

$$\frac{10}{200} \times 100 = 5\%$$

Let us then determine the total content of carbon.

Carbon is contained both in the titanium-tungsten carbide and in the tungsten carbide.

The content of carbon in the complex carbide usually amounts to 9.5 per cent; and in the tungsten carbide, to 6 per cent. When checking the content of carbon in each particular case, it is necessary to take its content in both the carbides in accordance with the chemical analysis data for the batch which has been used for preparing the mixture.

Let us calculate the content of carbon in the complex titanium-tungsten carbide:

$$\frac{41.66 \times 9.5}{100} = 3.95 \text{ kg}$$

The content of carbon in the tungsten carbide will amount to

$$\frac{138.34 \times 6}{100} = 8.30 \text{ kg}$$

The total amount of carbon in the mixture will thus be equal to

$$3.95 + 8.30 = 12.25 \text{ kg}$$

Determine the percentage of carbon in the mixture:

$$\frac{12.25 \times 100}{200} = 6.12\%$$

Comparing the figures obtained with the requirements of technical standards for the chemical composition of the

mixture of the given composition convinces us that the calculation has been made properly.

The same procedure is employed for checking the calculation of a charge for a two-component mixture.

5.10. Procedure for Preparing Mixtures

The charge for preparing mixtures is made up of the constituents corresponding to the given grade, taken in a quantity equal to that calculated.

The components are charged into a mill which has previously been filled with hard-alloy balls. Alcohol is first poured through the charging opening, followed by the powdered components of the mixture. After the charging has been completed, the mill drum is closed by a cover provided with hermetical packing, whereupon the mill is started. Prior to starting the mill, a trough is placed under the drum, in which water from the water-supply system is circulated for cooling the mill. On completing grinding of the mixture, the mill is discharged in the following manner. The pulp in the drum is diluted by pouring some alcohol (about 15 to 20 litres) into it 30 to 40 minutes before completing the grinding operation. Then the mill is stopped, the cooling trough is removed, and a grid cover is inserted into the charging opening to retain the grinding bodies; the liquid mixture is drained by being filtered through a 0056 to 0045-mesh sieve into a vessel.

Alcohol (about 10 to 20 litres) is then added to the mill, the charging opening is covered with a solid cover, and the mill is started again. The alcohol with the remainder of the mixture is added to the main mass. Such washing may be repeatedly carried out until the surfaces of the mill lining and the balls are clean.

When discharging mills of some other designs, instead of draining, the pulp is forced out by compressed air.

As has been pointed out above, the mixture discharged from the mill is filtered through a sieve. Filtering is carried out with a view to preventing uncrushed carbide particles and pieces of the grinding bodies from getting into the mixture. The filtering of mixtures subjected to wet grinding has

a direct bearing on the quality of the mixtures and, hence, on the quality of the alloys manufactured from them.

According to the existing filtering technique, the mixed pulp is poured either onto a stationary sieve or onto a pneumatically-driven vibrating sieve. The second method presents a number of advantages over filtering through a stationary sieve, where the pulp of mixtures of many grades, especially fine-grained, passes through the grid with difficulty even if alcohol is repeatedly added in order to dilute the mixed pulp to the required consistency.

When use is made of vibration filtering, the passing rate of the mixture is increased without increasing the degree of contamination of the mixture.

The vibration method of filtering the mixed pulp is capable of speeding up the manufacturing process and considerably facilitating the labour involved.

5.11. Drying Mixtures after Grinding

In order to remove liquid from a mixture subjected to wet grinding, the mixture is dried in special apparatus called distillers. If small amounts of a mixture must be dried, drying cabinets are used.

The mixture is heated to a temperature of 90 to 120° C, and the alcohol vapours evaporating from it are withdrawn from the drying cabinet or chamber into a reflux condenser; the condensed alcohol is reused in the manufacturing process. The alcohol vapours are recovered to an extent of 85 to 90 per cent, depending on the design of the distiller.

The dried mixture is composed of soft, easily disintegrating lumps. If air penetrates into the drying chamber (because of insufficient airtightness of the distiller), the mixture is oxidized; this may also occur at the instant of discharging the hot mixture. Oxidation may be so intense that sparking of the powder is observed. Cobalt is oxidized first because it readily reacts with oxygen. The reaction of cobalt with oxygen proceeds with the evolution of a large amount of heat, which is sometimes so intense that the carbide particles are also oxidized.

Fine-grained mixtures and mixtures with a high cobalt content are especially liable to oxidation.

In order to avoid oxidation of mixtures in the course of their drying, hermetically sealed apparatus is used and rather long cooling of the mixture in the distiller is carried out. Sometimes the container (tank) with the mixture discharged from the distiller, is filled with carbon dioxide and tightly closed.

The distiller is a cylindrical vessel with double walls between which either steam or water at room temperature is passed. The alcohol vapours condense in a water-cooled coil, the condensate being collected in a drain tank. On the charging side the distiller is provided with a tightly fitting cover.

Distillers are subdivided into two types according to the charging method employed. Into the distillers of one type the mixed pulp is charged in special boats of stainless steel, which are placed inside the distiller. In this method of charging, several boats are simultaneously placed inside the distiller. The boats are filled with the pulp to one-half—one-third of their height.

Distillers of the other type are directly filled with the mixed pulp without using boats for this purpose. To ensure uniform drying of the mixture in such a distiller, it is continuously mixed by means of a mixer.

This design of distillers has the following advantages:

1. High productive capacity.
2. The entire quantity of mixture discharged from the mill is dried in one apparatus under the same conditions.
3. Continuous intermixing of the mixture during its drying, which improves the degree of its drying and its homogeneity.
4. Mechanized servicing without having recourse to manual labour.

The mixture is dried in the distiller during 9 to 14 hours. On completing the drying operation, the supply of steam is disconnected, and the mixture is cooled with water supplied between the walls of the distiller cylinder during 6 to 10 hours.

Fig. 5.4 shows schematic drawing of two types of distillers; Fig. 5.5, a schematic drawing of a drying cabinet. The housing of the drying cabinet is made of sheet iron in two walls between which there is provided an insulating material

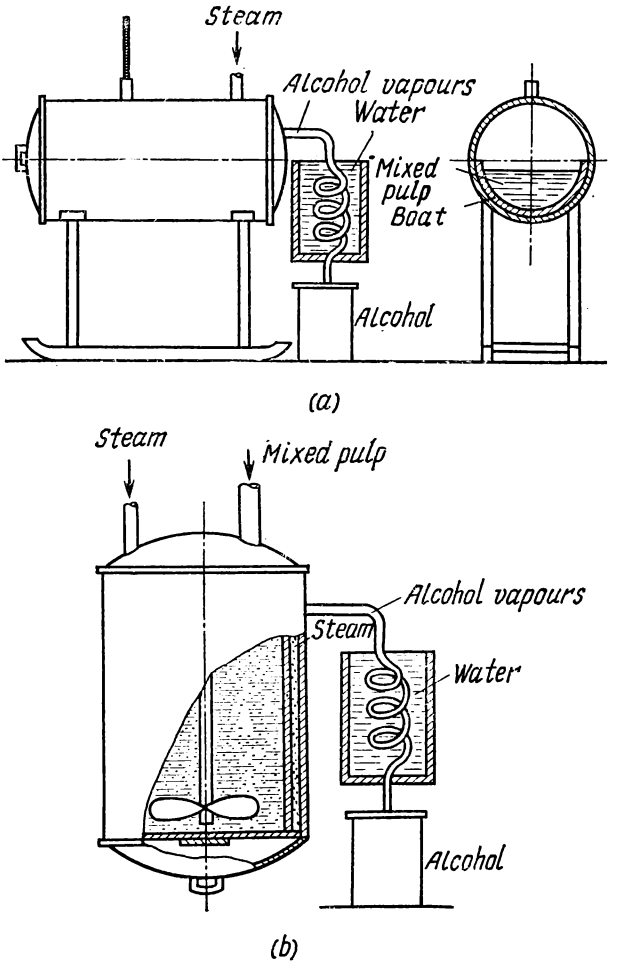


Fig. 5.4. Schematic drawing of distillers
(*a*) with charging boats; (*b*) with mechanized charging of mixture

for reducing heat losses through the housing. The front of the cabinet is provided with a tightly closing door through

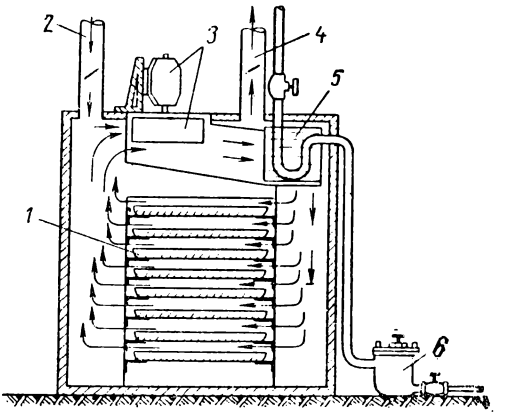


Fig. 5.5. Schematic drawing of a drying cabinet
1 — trays with the material to be dried; *2* — air-supply pipe; *3* — motor and fan; *4* — air-exhaust pipe; *5* — steam heater; *6* — steam trap

which the mixture is charged. Arranged inside the drying cabinet are hollow racks, on which are placed trays with the

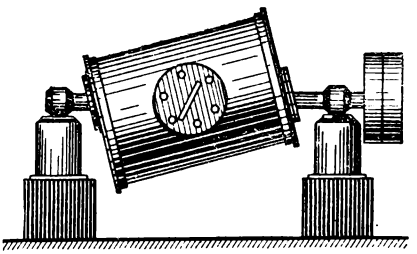


Fig. 5.6. Mixer of the 'drunken barrel' type

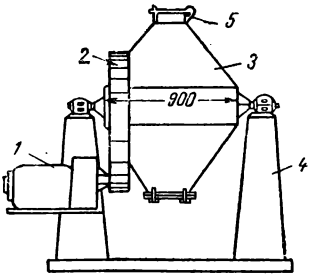


Fig. 5.7. Conical mixer
1 — motor with a reduction gear; *2* — driving gear; *3* — drum; *4* — support complete with bearings; *5* — discharge opening

mixed pulp. The pulp is heated by steam circulating inside each rack. In the drying process the mixture is continuously mixed by hand. When drying the mixture in the drying cabi-

net, the alcohol vapours are not recovered. The frequent opening of the cabinet door for mixing the mixture results in strong oxidation of the latter and sometimes causes its ignition. Drying a mixture in a cabinet is generally considered to be uneconomical, unproductive, and laborious.

When preparing mixtures, it is always possible that there are some deviations from the specified composition and physical condition; this makes it necessary to homogenize the batch. For this purpose, separate portions of a mixture are mixed into one batch. This mixing operation is effected in mixers of the type called 'drunken barrel' (Fig. 5.6) or in conical mixers (Fig. 5.7). On completing this operation, the mixtures are screened.

5.12. Screening Mixtures

Screening is effected in order to separate out impurities from a mixture, and also to loosen up and homogenize it. For this purpose, various sieve gauzes are employed, such as of silk, copper, or bronze. The most extensively used is bronze gauze. The sieves are distinguished by the size of the apertures and thickness of the wires they are made of.

In the production of hard alloys, use is made of sieves having a mesh size from 0.15 to 0.045 mm. When screening the mixture of a combined batch, sieves having a mesh size from 0.11 to 0.09 mm are employed.

In the case of so-called free screening, the sieve usually allows that part of the powder to pass which is composed of easily disintegrating lumps. Extraneous matter and large-size, strong grain aggregates are retained on the sieve in the form of the so-called oversize, which is collected and added to the waste (more frequently in lumps) to be reprocessed.

Powders are mainly screened on mechanical sieves of various designs. The sieves may be subdivided into two principal types: lever and vibrating. In the lever-type sieves, the container fitted with a mesh bottom is set into a vibrating motion by a system of levers actuated via a multiple V-belt drive (or Texrope) from an electric motor (Fig. 5.8). In this design, the mixture is usually screened owing to the horizontal motion of the sieve.

In a vibrating screen (Fig. 5.9), the container fitted with a mesh bottom (sieve) is attached to a frame connected with springs. Provided on the frame are bearings in which there rotates a small shaft with an eccentric lug which, when

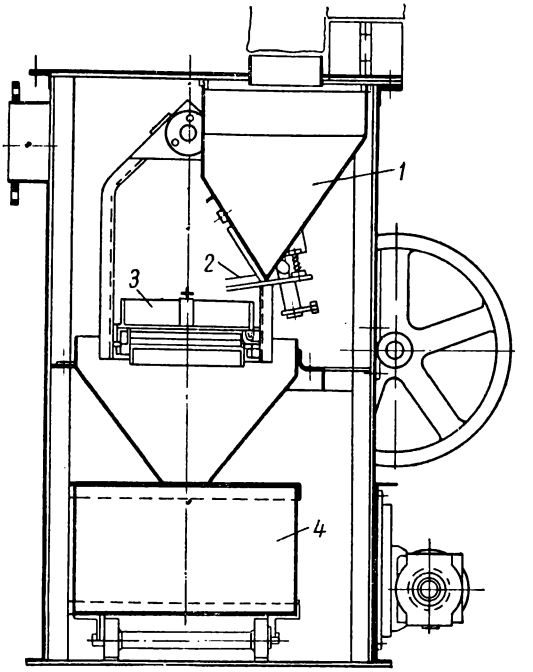


Fig. 5.8. Schematic drawing of a lever-type screen
1 — hopper; *2* — trough; *3* — sieve; *4* — trolley

rotating, makes the frame vibrate. In this case, the sieve moves vertically. The vibrating screen is designed to oscillate at a somewhat higher frequency than the lever-type screen, which results in a higher capacity of the former.

Fig. 5.10 shows the design of a suspended vibrating screen. In this screen, the sieve is also vibrated by means of an eccentric device mounted on the shaft of an electric motor. When rotating, the eccentric impinges upon the screen frame which transmits its vibrations to the sieve. The device

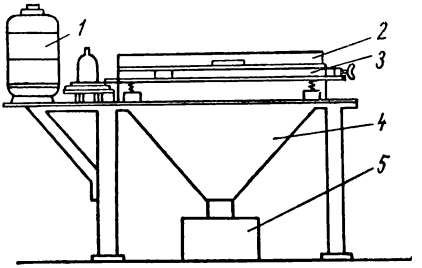
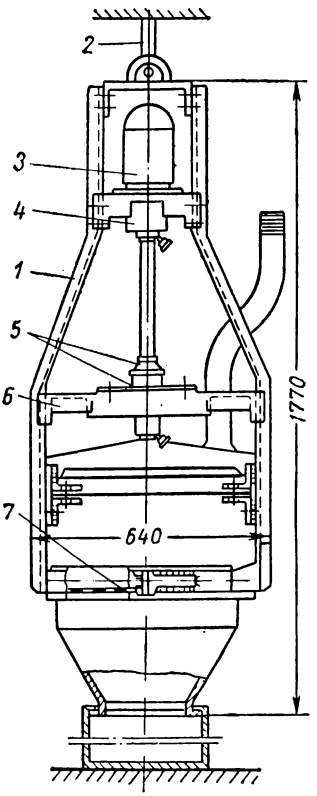


Fig. 5.9. Schematic drawing of a vibrating screen

1 — electric motor; *2* — container with a mesh bottom (sieve); *3* — spring-loaded round frame; *4* — funnel for sifting powder; *5* — tank for collecting the sifted powder

as a whole is freely suspended from a hook; this assures high frequency of oscillations (that are not hindered by any braking forces) and mobility of the frame together with the sieve at the instant they are drawn aside in order to set in place a collecting tank for receiving the mixture being sifted. Owing to the high frequency of oscillations, suspended vibrating screens are capable of attaining a productive capacity of 20 to 30 kg of powder per hour.



The vibrating screen of this type is also the most efficient for screening fine-grained and extremely fine-grained mixtures that usually clog the sieve nettings of other designs and require forced screening.

In screens of all designs the mixture to be screened is fed onto the sieve netting either from a charging hopper or ma-

Fig. 5.10. Schematic drawing of a suspended screen

1 — frame; *2* — suspension hook; *3* — motor; *4* — bearing; *5* — eccentric device; *6* — cross-piece; *7* — sieve

nually. The sifted powder through a funnel falls into the collecting tank. When screening the mixture a large amount of dust is formed. In order to reduce the losses of the mixture and improve the working conditions, the sieve containers are tightly closed with covers, whereas the screens themselves are placed in dust-collecting chambers made like fume chambers.

In the course of screening the condition of the sieve gauze should be closely watched; for the smallest defects (ruptures) would allow impurities and various inclusions to get into the mixture, which would result in obtaining an alloy of poor quality.

Mixtures are usually collected and stored in containers made of stainless steel, which is less susceptible to corrosion and is a sufficiently strong material for transferring heavy powders. These containers are generally tanks of different capacities, which are provided with tightly fitting covers to prevent impurities from getting in. It is recommended that the tanks with the powders be stored in special places that are protected against the penetration of moisture and from being heated by various heat sources. When preparing mixtures, care should be taken that all types of equipment (grinding, screening) should be clean because work in dirty equipment results in obtaining contaminated mixtures.

The prepared mixture is thoroughly checked with a view to determining its mechanical properties and structural characteristics. The object of this checking consists in evaluating, in the course of this intermediate operation, the suitability of the mixture for subsequently manufacturing the alloy from it.

For this purpose, the mixture is tested as follows. A small batch (or sample) of the mixture is subjected to all the operations to which the entire batch of the mixture must subsequently be subjected to produce the alloy.

A sample is selected with a probe from several parts of the tank in which the mixture batch is stored; the probe should dip into the entire depth of the tank. Then the sample is subjected to control sieving by sifting it through a sieve of the same mesh size through which the entire mixture has been screened. If in this test, all of the mixture passes through the sieve without any oversize remaining, the screening

operation is considered to be of good quality. If after the test screening some oversize does remain, the entire mixture is rescreened.

A smaller representative sample (1.5 to 2 kg in mass) is taken from the screened sample by the quartering method; a small part of the sample is subjected to chemical analysis, while the remainder is mixed with a solution of synthetic rubber in petrol. From this sample are briquetted test specimens $5 \times 5 \times 35$ mm in size (the size is indicated for sintered parts) and several articles in the shape of cutting or drilling parts, depending on the purpose of the mixture being tested.

All the articles are sintered according to the schedule for the composition of the mixture which has been taken for testing. After sintering, the articles are tested for determining the following characteristics:

1. Density (by weighing the articles in air and in water).
2. Bending strength.
3. Rockwell hardness.
4. Coercive force.
5. Cutting or drilling properties.
6. Macrostructure.
7. Microstructure.

On obtaining the above-mentioned characteristics, it is possible to evaluate the quality of the mixture and the possibility of passing it on for the subsequent operations.

5.13. Types of Rejected Mixtures and Methods for Their Correction

When preparing mixtures, they may be rejected for the following reasons: inappropriate chemical composition, contamination, oxidation, improper granularity, and bad mechanical properties. A mixture is rejected on account of its chemical composition when the contents of the components constituting the mixture do not conform to those specified in standards. This type of rejection may be caused either by faulty calculation of the charge for preparing the mixture, or by incorrect weighing of the components charged into the mill. Deviations in chemical composition are most probable

for cobalt, carbon, titanium, and tantalum (in the case of titanium- or tantalum-containing mixtures).

Incorrect chemical composition, in most cases, can be corrected. To this end, separate batches of mixtures are mixed (that are sometimes specially prepared for this purpose, precalculating the content of the constituent required for correcting the other mixture) or by adding the necessary amount of the components to a ready mixture.

It is better practice to add one mixture to another rather than to add the deficient components, because in this case the mixtures have almost the same granularity. Addition of the deficient components requires additional grinding, which would result in greater pulverization of the matrix mixture.

The following examples will illustrate different calculations aiming at correcting the chemical composition of a mixture.

Example 1. A 200-kg batch was prepared of a grade BK6 mixture containing 5 per cent Co instead of 6 per cent as required by technical specifications. What amount of cobalt should be added to the batch in order to raise the cobalt content up to the required level?

The amount of cobalt present in the mixture is

$$\frac{200 \times 5}{100} = 10\,\text{kg}$$

The amount of cobalt corresponding to 6 per cent of the mixture is

$$\frac{200 \times 6}{100} = 12\,\text{kg}$$

The amount of cobalt which must be added to the mixture is

$$12\,\text{kg} - 10\,\text{kg} = 2\,\text{kg}$$

Example 2. A 200-kg batch was prepared of a grade BK6 mixture containing 8 per cent Co instead of 6 per cent. Determine the amount of tungsten carbide, which must be added to the mixture in order to make the cobalt content in the mixture correspond to the specified value, i.e., 6 per cent.

The amount of cobalt in the mixture is equal to

$$\frac{200 \times 8}{100} = 16 \text{ kg}$$

The amount of tungsten carbide is equal to

$$\frac{16}{200 + x} \times 100 = 6$$

where x is the amount of tungsten carbide; $x = 66$ kg.

Checking. Determine the cobalt content in the mixture after adding tungsten carbide:

$$\frac{16 \times 100}{266} = 6\%$$

After the addition of tungsten carbide the cobalt content will correspond to the requirements of the technical standards. Hence, the calculation has been carried out properly.

The chemical composition of the aforementioned mixtures can be corrected by intermixing two batches of different mixtures. To this effect, it is necessary to determine the amounts of both mixtures, which should be taken for mixing.

The mass of mixture A is determined with the aid of the following formula:

$$A = \frac{K(b - c)}{b - a}$$

where A = amount of a mixture having a cobalt content of a %, kg

K = amount of freshly prepared mixture (after mixing), kg

b = cobalt content in mixture B, per cent

c = cobalt content in the freshly prepared mixture (after mixing), per cent

The amount of mixture B is found as the difference

$$B = K - A$$

For the sake of clarity the letter symbols will be replaced by numerical values.

Example 3. Prepare 200 kg of a mixture containing 6 per cent Co from two batches of mixtures containing 9 and 3 per cent Co, respectively.

The amount of one mixture is

$$A = \frac{200\,(9-6)}{9-3} = 100\ \text{kg}$$

The amount of the second mixture is

$$B = 200\ \text{kg} - 100\ \text{kg} = 100\ \text{kg}$$

Checking is necessary to confirm the correctness of the calculation.

Checking. The amount of cobalt in mixture A is

$$\frac{100 \times 3}{100} = 3\ \text{kg}$$

The amount of cobalt in mixture B:

$$\frac{100 \times 9}{100} = 9\ \text{kg}$$

The cobalt content in the freshly prepared mixture is equal to

$$\frac{(3+9)\,100}{200} = 6\%$$

The calculation has been carried out correctly. When correcting mixtures having deviations in the chemical composition with regard to other components, calculations similar to those given above must be made.

Contamination of a mixture is due to extraneous matter or uncrushed conglomerates getting into it after filtering or screening. Sometimes, contamination results from a rupture in the sieve netting occurring during filtering or screening.

Impurities in the mixtures can be detected by observing the macro- and microstructure of specimens. The impurities have the form of large pores, separate blowholes or crevices in the fracture or microsection of a specimen.

Defects of this type can be corrected by rescreening the mixture. If this proves to be ineffectual, the contaminated mixture will have to be filtered. In this case, the mixture is again charged into a mill, into which is also poured the required amount of alcohol. The mill is actuated for a period of 2 to 4 hours in order to assure additional intermixing of the mixture; then it is discharged from the mill. After dry-

ing the mixture batch, a sample is again taken and examined to check the structure of the alloy. If the structure of the test specimens corresponds to the technical requirements, i.e., if it has no blowholes, large pores, or crevices, such a mixture will be passed on for subsequent operations.

In case the presence of the aforementioned defects is detected in the structure of the test specimens, the mixture will have to be reprocessed according to the waste-treatment flowsheet.

Oxidation of a mixture. Mixtures can oxidize in the course of their drying in distillers. The degree of oxidation may be slight or very strong. A slight degree of oxidation does not result in any external changes in the mixture. In this case, the degree of oxidation can be evaluated by the amount of oxygen contained, which is determined by chemical analysis. Strong oxidations can be detected by external examination, as the traces of tungsten oxides become distinguishable in the mixture. Similar to impurities, the oxidation of a mixture causes the formation of various structural defects. They comprise blowholes and large pores, the characteristic feature of these defects being their colouring ranging from black to brown with a reddish tinge. Such mixtures are extremely difficult to correct because it is almost impossible to determine the degree of oxidation in each particular case.

The oxidized mixtures can be corrected by reducing them in a hydrogen atmosphere. This operation, however, which is conducted at fairly elevated temperatures (of the order of 650 to 700°C), is conducive to the coarsening of the mixture resulting from agglomeration of particles. That is why the reduced mixtures require additional grinding, the schedule of which is different for each mixture, depending on the degree of agglomeration. After the additional grinding of the mixture, the standard sintering schedule, as a rule, does not ensure obtaining the proper mechanical properties, the desired level of which can be attained only by selecting a special sintering schedule. In the case where the level of the mechanical properties of the alloys falls below the specified values, the mixture is rejected and passed on for reprocessing as a waste product.

Deviations in the granularity of an alloy. Each alloy grade is characterized by a corresponding set of grains of

the carbide phases, which assure the required properties. The grinding schedules for mixtures are commonly selected so as to obtain the required granularity of the alloy. Nevertheless, in practice, there are sometimes observed cases of deviations from the specified structure, which result from nonobservance of the mixture grinding schedule, e.g., stopping the mill earlier than required, letting the mill rotate longer than prescribed, deviations in the charge of grinding bodies, in their size, etc. The departure of a mixture from the required granularity is usually detected in the course of metallographic examination of an alloy by counting the number of grains of the carbide phases. Structural changes result in changes in the mechanical properties of an alloy, because the alloy structure and its properties are interrelated. Defects in the granular composition of alloys can result in their poor physicomechanical properties. Correction of such defects requires either additional grinding of the mixture (if its granularity is too coarse due to insufficient grinding) or selecting a sintering schedule which would assure attaining an alloy of the required granular composition in case of regrinding the mixture.

Faulty preparation of mixtures has a very detrimental effect on production inasmuch as a mixture batch of considerable mass will have to be rejected at once. In order to prevent rejects, it is necessary to strictly observe all the schedules of the processes specified in technical instructions, as well as the rules for servicing the processing equipment.

CHAPTER VI

Manufacture of Metal-Powder Products

6.1. Methods of Briquetting

A pressing or briquetting operation envisages obtaining parts of a predetermined shape. Powder mixtures of carbides with a bonding metal (cobalt) are first pressed into briquets of various shapes, which are then sintered. The pressing process involves changes in the structure and properties of powders.

Pressing considerably increases the contact area between particles, imparts the required strength to a briquet, disintegrates the conglomerates of particles and sometimes even the particles themselves. In the course of pressing there may simultaneously occur elastic, brittle, and plastic deformation of the particles. There are known the following pressing or briquetting methods: hydrostatic, nozzle, dross casting (pouring slurries into provisional moulds), hot, explosive, and die pressing.

Hydrostatic pressing consists in placing a powder into an elastic envelope (usually rubber 0.1 to 0.15 mm thick) which is subjected to uniform all-round compression under the action of a fluid (water, oil, glycerine).

The envelope is inserted into a perforated steel or plastic case having the section of the given shaped part, which is closed on both sides with special rubber plugs.

On relieving the pressure, the envelope returns to its former dimensions, while the briquetted part is easily extracted.

Figure 6.1 represents a schematic drawing of a hydrostatic pressing installation.

In the course of hydrostatic pressing, the particles of powder move to the centre of the blank under the effect of hydrostatic pressure. In this case, the external friction does not act; this allows the density to be equally distributed

throughout the entire volume of a part, independent of its overall dimensions and obviates any warpage of the form and the formation of crevices during the sintering operation thanks to uniform shrinkage.

The absence of external friction enables a considerably lower specific pressure to be applied than that applied in

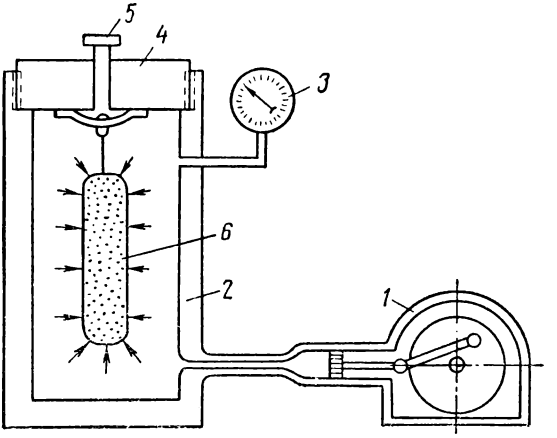


Fig. 6.1. Schematic drawing showing a hydrostatic briquetting installation

1 — high-pressure pump; *2* — working chamber; *3* — pressure gauge; *4* — seal; *5* — valve; *6* — blank

the course of ordinary pressing operations, which permits large-size parts of complicated shape to be manufactured.

Nozzle of mouthpiece pressing consists in that a mixture prepared with the use of a plasticizing agent is extruded through draw plates of various shapes (Fig. 6.2).

In nozzle pressing of mixtures, paraffin or wax may be employed as the plasticizer, the content of which in a mixture ranges from 5 to 11 per cent by mass, which corresponds to as much as 35 to 65 per cent by volume.

The plasticizer content in the charge mainly depends on the granularity of the powder mixture being pressed, the section of the part being briquetted, and on the pressing speed.

When mixing, it is necessary to distribute the plasticizer very carefully among the powder particles, in order to

facilitate the outflow of the mass through the nozzle. Homogenization of a mixture, i.e., bringing it to the state in which all the powder particles are uniformly intermixed

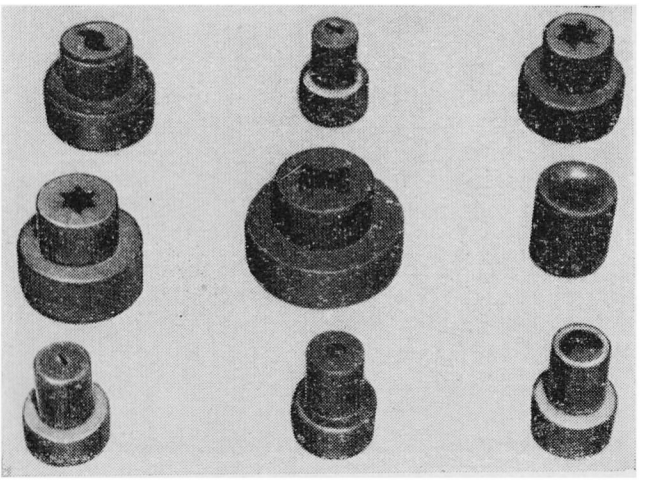


Fig. 6.2. Die holes of different profiles and punches for extruding shaped articles

with the plasticizer, is effected with preheating. The duration of this process depends on the amount of the plasticizer added, the granularity and composition of the mixture.

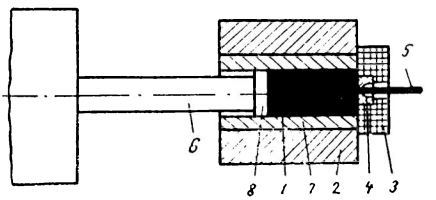


Fig. 6.3. Schematic drawing illustrating nozzle briquetting
1 — blank; *2* — receiver; *3* — die holder; *4* — die; *5* — the part being briquetted; *6* — piston; *7* — sleeve; *8* — press washer

Mixtures of high dispersion and with a high cobalt content homogenize at a faster rate. An increase in the content of paraffin markedly reduces the outflow pressure

In the nozzle-briquetting method, especially great care should be taken with the preparation of a mixture, in order not only to achieve uniform distribution of the plasticizer in the mixture, but also to compact it by removing from it the remaining air, which contributes to the formation of swelling on the surface and blowholes inside a briquetted piece.

To this effect, the mixture is pressed into briquets under a specific pressure of the order of 2000 kgf/mm^2. Pieces are extruded on hydraulic presses. Fig. 6-3 schematically illustrates the nozzle-briquetting procedure.

The plasticized mass is extruded with preheating up to a temperature of 35 to 45°C.

The production of pieces of good quality requires removing the plasticizer (the content of which in the briquetted pieces is considerable) prior to their final sintering. For this purpose, a low-temperature sintering is first conducted at a relatively slow rate of heating the pieces.

The nozzle-briquetting method allows the manufacture of comparatively long pieces having a small section, such as pipes, rods, boring bits, etc.

At the present time, the application of the nozzle-briquetting method is steadily growing.

Dross casting. The essential feature of the dross casting method consists in that a powder mixture, which has been pressure-mixed with a plasticizing agent (paraffin or water), is cast in a sectional mould which may be made of gypsum, ceramic or metal. If the mixture has been premixed with water, the dross is cast in a gypsum mould which is capable of absorbing moisture. The dried piece is extracted from the mould and subjected to final drying. To prepare the dross, fine-grained powders are used, because coarse-grained powders are incapable of producing a good suspension.

This method allows the production of pieces having a comparatively high initial porosity. Nevertheless, on sintering, the density of the pieces is fairly high and uniform.

This method can be used to manufacture pieces of especially intricate shape which cannot be manufactured by other methods.

Hot briquetting. In hot briquetting, the processes of pressing and sintering are combined; that is why hot briqu-

etting is used to produce pieces, that are already sintered. The hot-briquetting temperature generally ranges from 0.5 to 0.8 of the melting point of the main component. Owing to preheating, the compaction process with hot briquetting proceeds at a faster rate than when the briquetting and sintering operations are effected separately. The hot-briquetting method is suitable for obtaining pieces that are almost free from porosity.

In hot briquetting, as in ordinary pressing, the behaviour of the powder depends on the characteristics of the powder mixture but in hot briquetting, the powder characteristics affect the compressibility of the mixture to a smaller degree.

The density of the piece manufactured by the hot briquetting method, depends on the preheating temperature, the pressure applied and the holding time at the given temperature and pressure.

Hot briquetting enables the manufacture of pieces having, in the majority of cases, a fine-grained structure. This is explained by the relatively low temperature of preheating and short holding time used in the process. In hot briquetting the grain size depends on the grain size of the starting powder and on the briquetting pressure which provides favourable conditions for recrystallization.

The method of applying and relieving the briquetting pressure is of great importance for obtaining high-density coherent pieces. It is the best practice to apply the pressure to a specimen on heating it up to the required temperature in order to allow the gases to escape and thus eliminate the counterpressure of the gases in closed pores. It is desirable to relieve the pressure on cooling. In hot briquetting the specific pressure usually does not exceed 200 to 300 kgf/cm^2.

The hot-briquetting method is not extensively used in the hard-alloy (carbide) industry because of the low productive capacity of the process, the limited range of shapes and sizes of the parts that can be manufactured, and the variations in the cobalt and carbon content: cobalt is partially forced out from the piece, while carbon is likely to diffuse into the piece from the graphite press mould in which the briquetting operation is effected.

Explosive briquetting. The method of explosive briquetting in fluids and pistons is one of the versions of powder

briquetting. This method is suitable for manufacturing coherent pieces of difficult-to-compress compositions. The laws governing the explosive briquetting method are not yet fully understood. This method has not been put to industrial use in the manufacture of carbides.

Briquetting in press moulds or dies. The briquetting in press moulds or dies is the main technique of briquetting powder mixtures of carbides with a bonding metal (cobalt) when manufacturing cemented carbides, or sintered metal hard alloys.

The essential feature of this method consists in that the powder mixture is poured into a mould, in which it is compacted under the effect of an external pressure, whereupon

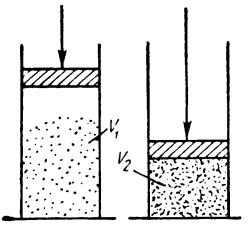


Fig. 6.4. Schematic drawing of compression of powder in briquetting

the briquetted piece is extracted from the press mould.

The following sequence of operations is applied in producing briquetted pieces:

1. Weight or volumetric batching of the premixed charge.
2. Pouring the batch into the press mould.
3. Briquetting.
4. Extraction of the briquetted piece from the press mould.

A briquetted piece will remain coherent and retain its shape only when the powder is strongly compressed in the press mould, and the separate powder grains adhere to each other.

Fig. 6.4 diagrammatically illustrates powder compression in the briquetting process.

From this schematic drawing, the following conclusions can be drawn:

1. The volume of powder (V_1) prior to compression is larger than its volume (V_2) after compression.

2. On reducing the original volume the powder grains may be deformed, i.e., change their shape and disintegrate.

3. After compression, the area of contact between the powder grains is greater than before compression.

The compression process is carried out in three stages. In the first stage, as the applied pressure increases, the grains are arranged in a more compact manner, but they are not deformed. The applied pressure continues to increase in the second stage, and the compactly packed grains offer resistance to compression. In the third stage of the process, the applied pressure exceeds the resistance of the grains to compression, and they are deformed. As a result, the grains are rearranged, and the powder is further compressed.

If the briquetting pressure applied is considerably increased, a very compact coherent piece can be obtained owing to the deformation of the grains and the increased contact surface. The powder grains used in the production of cemented carbides are very hard and strong; therefore, their deformation is insignificant.

The briquetting of powders for hard-alloy mixtures may be considered as a two-stage process: compaction and then resistance to compression.

In this particular case, the carbide grains do not disintegrate, and they are compacted owing to the distribution of finer grains among the coarser ones. Compression results in a reduction in porosity. In the first place, when compressing, the largest pores (those larger than the particles) are filled; this results in a reduction in the surface roughness of the particles.

Inside a briquetted piece there are created internal elastic forces applied in the direction opposite to the action of the external forces. Thus considerable stresses are set up in the briquetted piece. As a result, the briquet tends to expand after the pressure is removed. Slight expansion may occur in the pressing direction but the friction forces between the external surface of the briquetted piece and the press-mould wall interfere with the expansion and relieving of the elastic stresses.

As a result, the pressed briquet is securely held in the press-mould cavity. A certain pressure is required to extract the briquet from the mould.

The mathematical relation between the briquetting pressure and the extraction force is expressed by the following equation:

$$N_{ex} = \mu E P S_{lat}$$

where μ = coefficient of friction between the briquet and the press-mould wall
E = coefficient of lateral pressure
P = briquetting pressure, kgf/cm^2
S_{lat} = lateral surface of the briquet, cm^2

On removing the external load and the briquet from the press mould, the elastic forces begin to act on the briquet and expand it somewhat. This phenomenon is called elastic after-effect. The main factors affecting elastic after-effect are the degree of dispersity (pulverization) of the powders and the briquetting pressure. The smaller the dispersity, the greater the elastic after-effect, since an increase in the degree of dispersity results in an increase in the mechanical strength of the pressed briquet, which, in its turn, weakens the force of elastic after-effect. There also exists a definite relationship between the pressure applied and the elastic after-effect. The higher the briquetting pressure, the greater the elastic after-effect.

The elastic after-effect usually brings about a slight expansion of the pressed briquet, which amounts to fractions of a per cent of its initial size.

In spite of the effect of the elastic after-effect forces, the pressed briquet does not disintegrate; for the powder particles cohere owing to the action of mechanical forces of adherence and electrostatic forces of attraction, which exceed the elastic after-effect forces.

However, the elastic after-effect may cause disintegration of a briquet or development of so-called exfoliation cracks in it. These phenomena are especially favoured by an excessive briquetting pressure, as the elastic after-effect grows proportional to the specific pressure, whereas the mechanical strength of the briquet increases but insignificantly with the briquetting pressure.

When designing press moulds, the elastic after-effect must be taken into account.

The elastic after-effect forces acting in the briquet cross section may be determined from the formula

$$\delta_d = \frac{d_1 - d_0}{d_0} \times 100$$

where δ_d = elastic after-effect on the diameter, per cent
d_1 = diameter of the briquet on extracting it from the press mould, mm
d_0 = initial diameter of the briquet (or mould), mm

The elastic after-effect forces acting over the briquet height are equal to

$$\delta_h = \frac{h_1 - h_0}{h_0} \times 100$$

where δ_h = elastic after-effect on the height, per cent
h_1 = height of the briquet on extracting it from the press mould, mm
h_0 = briquet height in the press mould, mm

6.2. Properties of Briquetted Parts

Briquetted parts are evaluated by two main characteristics: density and strength. These two characteristics are interrelated. The higher the density of a briquet, the higher its mechanical strength.

The quality of the briquets is usually improved by increasing the aforementioned characteristics.

Briquet density. The main problem in briquetting powder mixtures of carbides with a bonding metal (cobalt) consists in obtaining a briquet having a sufficiently uniform density throughout its volume. This is explained by the fact that the degree of compacting a mixture in briquetting affects the shape and size of the compressed part during its subsequent sintering. When sintering, the compressed part undergoes shrinkage. If the compressed briquet possesses a uniform density throughout its entire volume, its shrinkage will also proceed uniformly in all directions. If the density of the briquet varies throughout its volume, shrinkage during sintering will not be uniform and this will cause distortion of the shape of the article and deviation from its specified dimensions.

However, when compacting powders there is observed considerable non-uniformity in the distribution of the briquetting pressure. Non-uniform density of a briquetted part is due to the effect of a number of factors, such as: friction of particles against each other and against the press-mould walls, the geometrical shape of the part, grain size and non-uniformity of grain sizes, the briquetting pressure, etc. The density may vary within a wide range, depending on these factors.

The coefficient of interparticle friction exceeds (by several times) that of friction of the powder against the press-mould internal walls, which is explained by the rough surface of the powder particles. The friction against the press-mould walls also results in considerable losses of the powder pressure. These losses mainly depend on the coefficient of friction of the material being briquetted, on the material the press mould is made of, the quality of machining of the press-mould walls, the height of the briquet being pressed, and the press-mould diameter.

The briquetted part has the highest density near the press-mould walls, just under the punch, and in the neighbourhood of the pad. Non-uniformity in the density distribution throughout the volume of the briquetted part grows as its shape becomes more intricate, because in this case it is difficult to transmit a uniform pressure in all directions.

Powders of various granularity can be packed more closely and fill up the free space better.

The grain size of a mixture greatly affects the density of the briquets. Coarse-grained and medium-grained powders are more readily compacted than fine-grained powders. That is why, when briquetting fine-grained powders, higher specific pressures are commonly applied than when briquetting coarse- and medium-grained powders, because fine-grained powders have a larger specific area and, consequently, higher interparticle friction.

Besides the granularity, oxides may also affect the compressibility of a powder. Oxides in powders are either formed by the oxidation of the particle surface on storing, or they are present in the form of inclusions that have partially not been reduced.

A considerable content of oxides results in a marked increase in the briquetting specific pressure. On applying the same specific pressure, articles manufactured from mixtures having a high content of oxides are characterized by an appreciably higher porosity than those manufactured from a mixture having but a small content of oxides.

The briquetting pressure is of great importance for obtaining a uniform density. This is connected with the rate

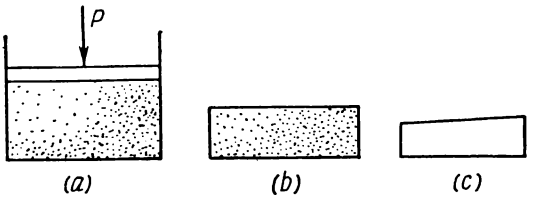


Fig. 6.5. Dependence of the density of a briquetted part and its shape after sintering on the distribution of a freely poured powder in the press-mould cavity

(*a*) distribution of a freely poured powder in the press-mould cavity prior to the application of pressure; (*b*) distribution of density in the briquetted part; (*c*) the shape of the part after sintering

of briquetting. When the pressure is low, the powder particles do not have enough time to be properly redistributed, and the mixture is not sufficiently compacted.

The briquetting rate can be increased by applying a higher pressure. The volume of a compressed briquet depends on the pressure applied when briquetting loosely poured powder.

The uniform density of briquetted parts largely depends on the distribution of the powder being pressed throughout the volume of the vessel into which the powder has been fed. If the powder is distributed uniformly, the density of the briquetted article will also be uniform. But if the powder is distributed unequally throughout the volume of the vessel it occupies, as is shown in Fig. 6.5, the shape and dimensions of the sintered part will be distorted.

Variation in the density of briquetted parts is observed in almost all cases, but it is necessary to select such an average density that the distortions in the shape and the deviations in dimensions of the sintered part are minimal. Such a possibility is realizable, and it should be used to

advantage when designing the press moulds. The dimensions of a press mould must be calculated with due regard to the various coefficients of shrinkage in different briquetting directions, determining these coefficients experimentally for a given part, in mass production.

An increase in the height of a specimen results in a greater variation in density, whereas an increase in its diameter is conducive to a more uniform distribution of density.

Non-uniformity in the distribution of density in pieces being briquetted may be materially reduced when recourse is had to two-sided pressing, where a pressure is applied to the briquet being compressed from two opposite sides, directed towards each other. For this purpose, a press with two plungers may be used, as well as a press provided with a plunger and a press mould of special design, in which the lower punch will be movable relative to the die walls.

When a briquet has been obtained by two-sided pressing, it may be considered as being composed of two parts, each two times shorter in height; because of that, the disadvantages characteristic of one-sided briquetting will be considerably reduced.

For manufacturing correctly shaped briquets, it is also necessary to apply high pressures; in this case, the briquets possess a fairly high density and shrink less when sintered. When briquetting carbide mixtures, the specific pressures applied usually equal 500 to 1500 kgf/cm^2, and the porosity of the briquets obtained from medium-grained powders averages 50 per cent. The relative density of a briquet and its residual porosity can be calculated from the following formula:

$$A = \frac{d_{br}}{d_c} \times 100$$

$$P = \left(1 - \frac{d_{br}}{d_c}\right) \times 100$$

where A = relative density of the briquet, per cent
d_{br} = density of the compressed briquet, g/cm^3
d_c = density of the compacted material, g/cm^3
P = the residual porosity of the briquet, per cent

The mechanical strength of a briquet is one of its main characteristics. If the mechanical strength of a briquet is

small, it may be destroyed due to the elastic after-effect or to the action of even slight mechanical loads.

The mechanical strength of the briquets should be sufficient to prevent them from being destroyed when subjected to the following operations: deburring, handling in drying, and sintering.

The mechanical strength of briquets is connected with the coherence of the powder particles. In this respect, a much smaller role is played by the forces of interaction between the atoms of the contact surfaces. The mechanical strength of the briquets depends on the size and shape of the grains, the surface condition, and the pressure applied.

Mixtures for hard alloys are mainly composed of grains of hard carbides that possess high mechanical strength and hardness. Added to the carbides is a bonding metal which due to its ductility increases the mechanical strength of the compressed briquet. Parts made of coarse-grained mixtures have a lower mechanical strength than parts made of fine-grained mixtures when the same briquetting pressure is applied and under other equal conditions. This may be explained by the fact that the fine-grained powders possess a larger specific surface; that is why in this case the mechanical cohesion forces are effective to the highest extent.

The more intricate the shape of the grains of the powder being compressed, the greater the probability of their cohering and of the contacting surfaces increasing, and hence, the greater the forces of mechanical cohesion.

The mechanical strength of briquets also depends on the surface condition of the grains. When the grains are coated with oxides or are cold-hardened, they are briquetted with difficulty, and the blanks composed of such grains have low mechanical strength.

The briquetting pressure greatly affects the mechanical strength. The higher the briquetting pressure, the higher the mechanical strength of a blank. As has been pointed out above, an excessive briquetting pressure results in the formation of exfoliation cracks, which is inadmissible.

The briquetting method practised does not envisage testing of the compressed parts for mechanical strength. In

this case, the technologist must depend on his own experience. In industrial practice, the mechanical strength of a compressed part is usually determined by pressing the specimen with the hand and characterizing the parts as 'weak' or 'strong'. However, such an evaluation is very subjective. With a view to eliminating the subjective factor when evaluating the mechanical strength of a compressed part, the pressure that assures the proper mechanical strength in a briquet is determined from the following formula:

$$P_g = P_{sp} \times \frac{S_{br}}{S_{pl}} = P_g \times \left(\frac{d_{br}}{d_{pl}}\right)^2$$

where P_g = gauge briquetting pressure, kgf/cm^2
P_{sp} = specific briquetting pressure, kgf/cm^2
S_{br} = area of the briquet being compressed, cm^2
S_{pl} = area of the press plunger, cm^2
d_{br} = diameter of the briquet being compressed, cm
d_{pl} = diameter of the press plunger, cm

6.3. Effect of Density of Briquet on Properties of Sintered Part

Ready-shaped specimens (i.e., when a part is briquetted to a prescribed shape) and those manufactured from a blank with subsequent machining differ in their wear resistance. The best properties are possessed by alloys that are briquetted under conditions minimizing the non-uniformity of density. That is why, when manufacturing alloys, it should be kept in mind that the cutting edges of parts having sharp angles ranging from 12 to 30°, as well as projections that materially differ in size from the remaining part of the blank are in the worst conditions for obtaining a high density. Therefore, it is recommended that such parts be briquetted as blanks rather than as ready-shaped briquets. In such a case, the probability of obtaining a non-uniform density is reduced, and hence, such defects as blowholes, crevices, and badly compacted spots in the working portions of parts are avoided, which, in its turn, is conducive to improvement of the operating properties of the alloys.

6.4. Preparation of Mixtures for Briquetting

In the production of hard alloys there are used carbide powders that are characterized by a very low plasticity. Therefore, to the mixture of carbides and bonding metal are added plasticizing agents that improve the fluidity of the mixture and assure lubrication of the grains, decreasing the friction between them. The plasticizing agent decreases the briquetting pressure required. The specific briquetting pressure largely depends on the quantity and quality of the plasticizing agent used.

Plasticizing agents should possess the following properties. They should

(a) wet the grains of the powder mixture well;

(b) easily dissolve in an organic solvent;

(c) be removed without traces of impurities from a compressed briquet on heating it up to a temperature of 600 to 750°C.

(d) increase the mechanical strength of a compressed briquet;

(e) produce no chemical effect on the components of the mixture;

(f) have no toxic effect on the servicing personnel.

The aforementioned requirements are met by the following compounds: a solution of synthetic rubber in petrol, a solution of glycerine in alcohol, paraffin or its solution in petrol, an alcoholic solution of glycol, a solution of camphor in petrol, and oleic acid.

The synthetic rubber solution is the most extensively used plasticizing agent. The advantage of this plasticizing agent consists in that it imparts to a mixture good fluidity and assures high mechanical strength of blanks at a fairly fast briquetting rate. The disadvantages of this plasticizing agent are: rubber is not completely removed from the briquetted part so that up to 0.1 to 0.2 per cent of free carbon remains after sintering; on long storage, the gluing properties of rubber deteriorate. That is why recently the use of paraffin as the plasticizing agent has been steadily growing.

The use of paraffin makes it possible to considerably increase the briquetting pressure without developing so-called

'exfoliation', which enables parts of a very high density to be manufactured.

Mixtures with paraffin permit parts to be manufactured, possessing much higher mechanical strength and better machinability as compared with parts made of mixtures with any other plasticizing agent.

Paraffin, however, has some disadvantages, such as: lower elasticity and gluing capacity as compared with rubber, which interfere with the compression of a mixture on presses operating with rapid application of pressure; impossibility of using automatic presses on account of the poor fluidity of the powder mixture; the necessity of using additional special furnace equipment to remove the paraffin prior to the final sintering of the parts.

The remaining plasticizing agents (glycol, camphor, oleic acid) suffer from a serious disadvantage: the mechanical strength of the blanks manufactured with their use is too low.

6.5. Procedure for Adding the Plasticizing Agent to a Mixture

Prior to use, a plasticizing agent is dissolved in a solvent. For instance, synthetic rubber in the form of small cut pieces is dissolved in petrol. The solution should be prepared very carefully in a clean vessel. The plasticizing agent should be dissolved as completely as possible. To prevent tiny undissolved pieces of the plasticizing agent from getting into the mixture, the solution is filtered through a wad of cotton and gauze folded in several layers. The prepared solution is tested to determine its concentration and ash content. If the solution concentration differs from that specified, the solution is diluted with petrol. The amount of petrol added can be determined from the formula

$$B = V\left(\frac{b}{a} - 1\right)$$

where B = amount of petrol, litres
V = quantity of synthetic rubber solution which must be diluted, litres
b = rubber content in the initial solution, per cent
a = rubber content in the solution which must be obtained, per cent

The process of preparing a mixture of powder and plasticizing agent, which is called the mixing operation, is carried into effect either manually on a metal tray by shovelling, in mechanical mixers, or on rotating steel rolls that are heated from inside.

The latter method is mainly employed for adding paraffin or wax to a mixture on a roll mixer, the main parts of which are steam-heated steel rolls that are driven by an electric motor through a transmission system. The transmission is designed so that one roll rotates at a faster speed than the other. As a result, one of the rolls supports the mixture, while the other transfers it into the 1-mm gap between the rolls, which facilitates homogenizing the mixture.

When treated on rolls heated up to a temperature of 70 to 80°C, the particles of the initial mixture of powders are thoroughly lubricated and glued together by the plasticizing agent. On further treatment, the rolled material begins to flow off the rolls in small streams that elongate and solidify as fibers, forming a 'wadding'. The fibers are rubbed through fine meshed sieves, which results in obtaining a loose, well-compressible powder. The angle of repose when feeding such a powder does not exceed 36°.

The method just described allows preparing mixtures having a uniform distribution of the plasticizing agent and capable of producing strong and dense blanks on briquetting. These mixtures may successfully be used for making plasticized blanks in the form of a thin sheet or band.

The preparation of a mixture on rolls, however, has not come to be used extensively on account of the small productive capacity of the process and rather large losses of the mixture during rolling.

When preparing a mixture with a solution of synthetic rubber, it is necessary to watch very carefully the quality of mixing, the concentration, and the amount of solution used. Thus, in manual mixing, the concentration of synthetic rubber in petrol varies from 4 to 5 per cent, whereas the quantity of the solution used ranges from 200 to 250 cm^3 per kilogram of mixture. In mechanical mixing, the concentration of synthetic rubber in petrol varies from 7.0 to 8.5 per cent, the quantity of solution per kilogram of mixture ranging from 120 to 150 cm^3.

PREPARING A MIXTURE WITH SYNTHETIC-RUBBER SOLUTION N A MECHANICAL MIXER

To prepare a mixture by the mechanical method, there are employed mixers consisting of a cylindrical vessel of stainless steel accommodating a double steel screw for effecting the intermixing operation. The vessel is provided with an exhaust vent for removing petrol vapours from the mixture. The solution is poured through a funnel inserted in an opening provided in top cover of the mixer. At bottom of the mixer there is provided an opening for discharging the prepared mixture onto a tray for drying. In addition to mixers of the aforementioned design, there are employed two-stage mixers comprising two communicating mixers provided with screw conveyers.

The two-stage mixers combine the processes of mixing and drying a mixture, as a result of which, the productive capacity is increased and additional floor space is obtained by dispensing with drying cabinets. The application of such mixers is, however, connected with certain difficulties: it is inconvenient to clean them and the mixture is additionally pulverized by disintegration of conglomerates during their long continuous friction against the screw conveyer.

High-quality mixtures can be obtained only if impurities are prevented from getting into the starting components of the mixture. For this purpose, prior to the mixing operation, both the mixer and funnel for pouring in the rubber solution must be carefully cleaned and washed with petrol. The required quantity of the synthetic rubber solution is poured into a funnel-shaped vessel. The powder mixture is fed into the mixer which is then closed with its cover, and the electric motor is started. The rubber solution is poured in a thin stream into the mixer through an opening provided in its cover. The mixture is continuously intermixed as the solution is poured in. After adding the entire amount of solution, the screw conveyer continues to rotate for some time. The bottom opening of the mixer is then opened, the prepared mixture is poured onto a tray and is distributed in a uniform layer on it; the tray is directed into a steam cabinet for drying. Since the mechanical mixer is provided with an exhaust vent through which the petrol vapours are intensely

removed, the prepared mixture is already somewhat dried in the mixer and, hence, does not require drying in a fume hood. The mixture is discharged from the mixer in the form of slightly moistened sticky clumps that need merely be dried for a relatively short time in a steam cabinet.

The mixture is dried in the steam cabinet on racks heated to a temperature of 70 to 90°C. During the drying operation, the mixture is intermixed with a view to achieving better and faster drying. The dried mixture is sifted through a sieve and put into containers with tightly closing covers in order to prevent contamination.

The main disadvantage of the mixing operation is that the mixture is heated in the course of its drying in the steam cabinet, and when the heated mixture is sifted, it is oxidized by the ambient air.

GRANULATION OF THE MIXTURE

The prepared mixture can be briquetted on hydraulic presses without any preliminary treatment. The mixture, however, possesses insufficient fluidity to be compressed on automatic presses. Therefore, the mixture must be granulated to give it the necessary fluidity. There are several methods for granulating mixtures.

Granulation in a rotary mixer. The mixture is placed into a mixer (conical or cigar-shaped) and treated there for a given period of time. On rotating, the mixture is rolled into spherical granules 0.5 to 3 mm in diameter. The granules are sifted out into fractions on a vibrating screen provided with a set of different sieves. The fraction composed of granules ranging in size from 0.5 to 1.5 mm are selected for briquetting. The coarser fraction of granules is rubbed through a sieve and then added to the next batch to be granulated. Finer granules, which are small and very hard clumps of the mixture, are withdrawn from the production cycle as waste.

The disadvantages of the aforementioned granulation method are the considerable amount of waste, and the high hardness of the granules, which requires high pressures for their compression, because of these disadvantages, other methods are now used.

Successive sifting of mixture on a vibrating screen through sieves with different meshes. In this case, on vibrating, the mixture is rolled into clumps of various sizes, which possess sufficient fluidity to fill the cavities of the mould.

The clumps are very soft and are readily compressed in the briquetting process, which almost eliminated rejects on account of faulty compression, as well as large pores in the parts briquetted from such granules.

In this method of granulation there is no waste because the part of the mixture which is not utilized as granules is added to the next batch to be granulated.

This granulation method has modifications, according to which, prior to granulation, the mixture is either moistened with petrol or prebriquetted, and then rerubbed. As a result of briquetting, the granules are somewhat hardened, but not to such an extent as to cause faulty compression.

All three methods can be used to obtain granules for manufacturing high-quality parts by briquetting on automatic presses. This is the granulation method now preferably used in industrial practice.

6.6. Briquetting of Mixtures

Two types of presses are mainly employed for briquetting mixtures, namely: hydraulic and mechanical presses (Figs 6.6, 6.7).

The operation of a hydraulic press is based on the principle of communicating vessels, one of which is the pump piston and the other, the working plunger of the press.

In this case, the basic law of communicating vessels is valid: the pressure of a fluid exerted on a piston is proportional to the area of the given vessel. If we denote the loads applied to the small and large pistons as P_1 and P_2 and the areas of these pistons as S_1 and S_2, we will obtain the expression

$$\frac{P_1}{P_2} = \frac{S_1}{S_2}$$

From this equation, the total pressure of the working piston P_2 can easily be calculated, using the pressure gauge readings, and the pressure required for compressing the given powder.

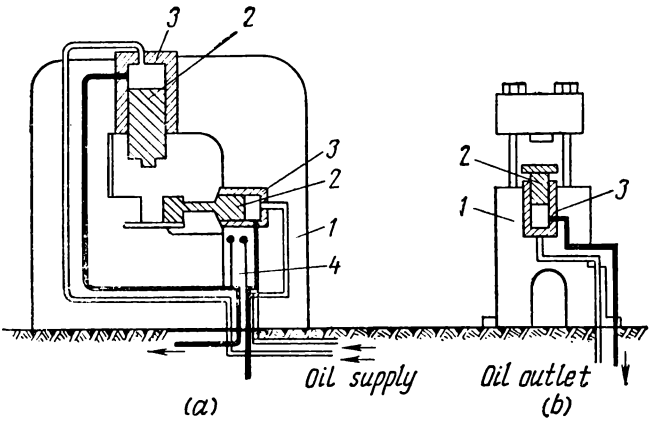


Fig. 6.6. Schematic drawing of a hydraulic press
(*a*) with vertical and lateral pressure; (*b*) with vertical pressure; *1* — stand; *2* — plunger; *3* — cylinder; *4* — control valves

Hydraulic presses of different designs may be employed but all of them are provided with a working cylinder and plunger.

The hydraulic presses commonly used in the production of sintered carbides possess two plungers: one vertical;

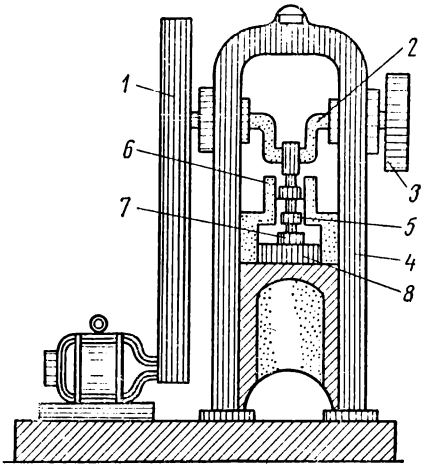


Fig. 6.7. Schematic drawing of a crank press
1 — driving pulley; *2* — crank; *3* — flywheel; *4* — stand; *5* — plunger; *6* — slide for the plunger rod; *7* — press mould; *8* — tightening piece for the press mould

the other, horizontal. The horizontal plunger is employed to clamp the press mould on the press table, while the vertical plunger is used to apply a pressure to the part being briquetted.

The capacity of hydraulic presses ranges from 50 to 300 tons. The hydraulic presses use oil or water as the working fluid. When oil is used, the corrosion of metal pipelines and press parts is avoided.

Mixtures are compressed on hydraulic presses in steel detachable press moulds according to the following sequence of operations:

1. Calculating the weighed portion of the powder mixture.
2. Weighing the portion out.
3. Pouring the weighed portion of powder mixture into the cavity (socket) of the mould, levelling the mixture, and inserting the punches.
4. Placing the assembled mould on the press table.
5. Applying lateral pressure.
6. Applying vertical pressure.
7. Holding the pressure applied.
8. Relieving the vertical pressure.
9. Relieving the horizontal (lateral) pressure.
10. Disassembling the mould.
11. Extracting the briquetted part from the mould.

Consequently, prior to briquetting, the weighed portion of mixture required for a given part must be calculated. It is found from the formula

$$G = V_{si}\gamma K$$

where G = weighed portion of powder mixture, g
V_{si} = volume of the sintered part, cm^3
γ = average density of the alloy of a given grade, g/cm^3
K = coefficient that takes into account the total losses of mass when briquetting and sintering

The mass losses include the amount of the powder mixture sticking to the walls of the mould, the amount lost on deburring, as well as the losses due to burning out of the plasticizing agent. The value of this coefficient usually

varies within 1.02 to 1.04. When briquetting plates to be machined, the weighed portion is calculated from the following formula:

$$G = \frac{V\gamma K}{R^3}$$

where G = weighed portion of powder mixture, g
V = volume of unsintered briquetted plate, cm^3
γ = average density of the sintered alloy of a given grade, g/cm^3
R = shrinkage coefficient of the alloy of a given grade
K coefficient that takes into account the losses on briquetting and sintering

The calculated portions may vary for each separate mixture to be briquetted by about ± 5 per cent, depending upon its compressibility.

A separate portion for each part is weighed out either on a technical balance or with the aid of an automatic batching device.

A loading funnel is used to feed the powder mixture into each mould socket, if it is a multisocket mould. This operation must be carried out with great care so that the mixture is not spilt and does not get into another socket; this would result in deviations from the prescribed dimensions of the parts on sintering them.

The articles may be briquetted either by applying a precalculated pressure to them, or by using a limiter in the case of mass production of parts of the same type. The limiter is a steel plate of a known thickness, which is designed to limit the motion of the mould punches.

In this particular case, the parts are briquetted according to a given thickness. The limiter is selected, when adjusting the press, to the calculated thickness of a given part, while taking into account the required strength of the briquetted piece. On completing the briquetting operation, the mould is disassembled on the working table, the plates are extracted from it and placed on a tray.

In addition to the hydraulic presses, the powder mixtures may be briquetted on mechanical presses provided with press moulds having a sintered carbide die. In the

mechanical presses the briquetting pressure is created by coacting mechanisms. These presses may be of the connecting rod-crank or lever-crank type. The mechanical presses, the capacity of which usually does not exceed 50 tons, are not employed for applying heavy briquetting pressures. They differ from the hydraulic presses in their high productive capacity owing to the fast rate of operation of the plunger. However, the press should not be allowed to operate at the critical speed; fast rates of applying and relieving the briquetting pressure may result in the development of cracks in the parts. The rate of briquetting on mechanical presses should not exceed 30 to 35 cycles per minute.

In addition to the aforementioned advantages, the mechanical presses also suffer from a serious disadvantage consisting in that they are incapable of assuring a gradual increase in the applied pressure like the hydraulic presses do. The mechanical presses apply the briquetting pressure only instantaneously; that is why the briquetting operation is effected with an abrupt jerk. The briquetting pressure is also relieved at a fairly fast rate. The aforesaid peculiar features of the operation of a mechanical press constitute the factor limiting the assortment of parts that can be briquetted on it.

The main constituent parts of a mechanical press are the plunger and press-mould sleeve accommodating the die and pushing-out rod.

Mechanical presses with a hopper containing the granules may be considered as semi-automatic presses, since the press-mould cavity is filled by volumetric batching, without any interference on the part of the operator in charge of weighing. For compressing parts on automatic presses there have recently been employed vibrating feeders allowing automatic batching of a mixture without subjecting it to previous granulation (Fig. 6.8).

Prior to briquetting, the press mould is placed in a case. The volume of the mixture is selected in accordance with the required thickness of the given part, specified in the drawing, since the remaining dimensions of the part are defined by the walls of the mould and are thus predetermined. The plasticized mixture is fed into the hopper. After starting vibrator *5*, the powder from the main hopper is

poured into auxiliary hopper *4* which is also provided with vibrator *5* and a level pick-up. On reaching the level of the feeler pin, the powder mixture is no longer fed into the auxiliary hopper. After starting the vibrator, the mixture from the auxiliary hopper fills the case which is reciprocating on the working table of the press. The vibrator is

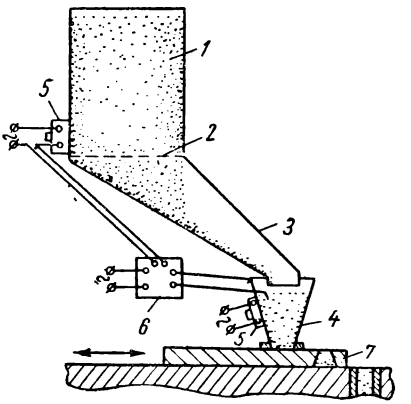


Fig. 6.8. Schematic drawing of a vibrating feeder

1 — non-granulated mixture; *2* — sieves; *3* — main hopper; *4* — auxiliary hopper; *5* — electric vibrators; *6* — level pick-up; *7* — case for press mould

switched off when the case moves away from the auxiliary hopper. When the case passes over the mould, the mixture is fed by means of a vibrator into the press-mould cavity. Vibration is stopped as soon as the case moves away from the mould. At this moment, the plunger goes down, presses on the die and forces it down, whereby the briquetting operation is effected. The press plunger goes up. The die occupies its upper position under the action of a spring. The lower punch pushes the part out of the press mould. The following movement of the case serves to push the part onto the conveyer. As has been mentioned earlier, the hydraulic presses use steel detachable moulds for briquetting parts.

Parts of a given shape may be manufactured in two ways: briquetting pieces in full conformity with the drawing as to their shape and dimensions, taking into account their shrinkage; and compressing a blank which must subsequently be machined.

Machining is conducted in those cases when the manufacture of parts is complicated by the difficulty of attaining uniform distribution of density. This mainly pertains to parts with bevels, chamfers, and conical portions.

Simple machining is effected on grinding machines and lathes. For this purpose, the grinding machines use abrasive wheels mainly consisting of silicon carbide, the granularity and hardness of the wheels being selected depending on the granularity of the mixture the article is made of. Lathes use tools fitted with steel or sintered carbide cutters.

The application of machining is conducive to improving the quality of the parts because all the faulty portions of a briquetted blank are thus removed. Testing for statical strength has shown that parts manufactured ready-shaped possess a bending strength that is 25 per cent lower than that of parts manufactured from blanks. It is the portion of the part adjacent to the chamfer that plays the main role in reducing its bending strength. Set forth below are the bending strength values in kilogram-force per square millimetre for plates, depending on the way they are manufactured:

Grade T15K6 alloy		Grade BK8 alloy	
manufactured ready-shaped	manufactured from a blank	manufactured ready-shaped	manufactured from a blank
72	110	148	176
74	104	144	175
90	114	122	165
85	96		

Machining is an extremely expensive operation, for it involves the formation of a great amount of waste containing valuable constituents; the procedure for reprocessing them is complicated on account of their being contaminated with abrasive dust coming from the grinding wheels.

Though machining leads to an increase in the production cost, it, nevertheless, contributes to improving the quality of the finished parts. That is why to reduce the production costs, machining should be applied only to articles posses-

sing sharp cutting edges, intended for heavy-duty applications. It is also necessary to reduce the machining allowances as much as possible, in order to diminish the losses and amount of the resulting waste.

The parts to be machined should be subjected to a preparatory treatment, as they must exhibit higher mechanical strength than briquetted parts. This preparatory treatment consists in drying or presintering operations.

In the course of drying, the solvent in the plasticizer is removed from the parts, which increases their mechanical strength. Drying contributes to relieving internal stresses, which prevents cracks from developing in sintering, especially when heating is conducted at a fast rate.

The drying operation is carried out in drying cabinets, using electrical or steam heating, or in special units (drying stoves) employing infrared rays for heating.

The drying stove is a chamber having in its upper portion infrared lamps arranged in a staggered order. The infrared lamps should be arranged so that the reflection of rays from one lamp is covered by the reflection of another. With such an arrangement of the lamps, no shadowy areas are formed, and the temperature produced by the radiation energy of the lamps will approximately be the same at any point of the light circle, with the exception of the most remote areas. The drying-stove bottom is heated by means of spiral elements. Exhaust fans are employed for carrying of vapours of petrol or any other solvent.

The trays with the compressed parts are placed on a conveyer moving at the bottom of the drying stove. The conveyer speed depends on the thickness of the parts being dried. The smaller the thickness of the part, the faster the conveyer speed. The temperature for drying the parts lies within the range of 150 to 200°C. It has been established that oxidation does not occur within this temperature range.

When drying parts in cabinets, heat is transferred by convection, and also from a more heated layer to a less heated one. When drying rather thick parts, the temperature drop between the surface and internal layers is considerable, and consequently, the internal portion of the part is heated to a lower temperature than the external one; hence, the degree of drying of the part also differs.

A quite different process occurs when drying with the aid of infrared radiators. The infrared rays are capable of easily penetrating into the very depth of the part. Therefore,

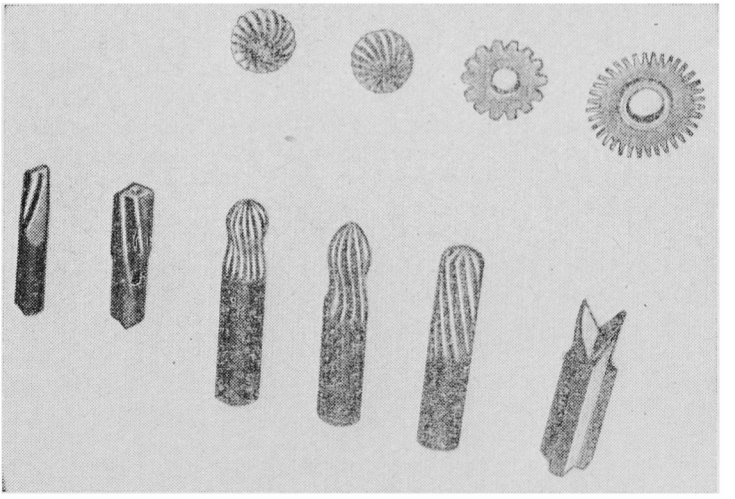


Fig. 6.9. Parts of intricate shape, manufactured from plasticized blanks

the entire part is equally heated throughout its thickness and dries uniformly.

Owing to the aforementioned advantages, drying stoves with infrared lamps have come to be extensively used in the production of cemented carbides.

Prior to complex machining, the parts are presintered at a temperature of the order of 650 to 750°C. Presintering not only facilitates evaporation of the solvent and burning out of the plasticizing agent, but also increases the contact surface due to welding of the carbide particles by heat, which contributes to increasing the mechanical strength of the part.

Presintering is carried out in electric furnaces provided with a graphite or alundum tube.

Some parts of very intricate shape (Fig. 6.9) are manufactured from plasticized blanks. Thanks to special tech-

niques used in preparing the mixtures, and to the addition of a plasticizing agent, the blanks thus obtained differ essentially from ordinary briquetted or sintered blanks. They are readily machined with cutting tools on conventional machine tools, such as lathes, drilling, and milling machines.

When machining plasticized blanks, there are formed chips in the form of scales or small sections of continuous shaving. The use of sharp tools for machining these articles enables very clean surfaces and sharp edges to be produced without any chipping. A machined blank is subjected to low-temperature sintering for removing the plasticizing agent, and then to final sintering.

When machining plasticized blanks, it is necessary to take into account the shrinkage value which is ascertained experimentally for each batch of blanks.

When machining plasticized blanks, the resulting chip can easily be reprocessed into a starting mixture. For this purpose, it is sufficient to remove the plasticizing agent by burning it out at a temperature of 600 to 700°C, and to grind it for disintegrating conglomerates that form when the plasticizing agent is being removed.

After drying and machining, the parts are examined by an inspector. Pieces suitable for sintering should meet the following requirements:

(a) the shape and dimensions of the part should correspond to the drawings for 'green' parts (just briquetted);

(b) the number and size (extent) of cracks, exfoliation, chipping off edges should not exceed the admissible value.

6.7. Basis for Calculation and Design of Press Moulds

The briquetted blank is sintered. In the course of sintering, shrinkage of the blank occurs resulting from the elimination of pores and also from a number of other physicochemical phenomena. The blank volume is decreased almost by 200 per cent, while the linear dimensions are reduced by 20 to 30 per cent.

Two types of shrinkage are distinguished: linear and volumetric. The ratio of the linear dimensions of a blank prior to its sintering to those after sintering is called linear shrin-

kage. For instance, if a briquetted plate prior to sintering had a length $l_1 = 25$ mm, whereas after the sintering its length became equal to $l_2 = 20$ mm, the coefficient of linear shrinkage is

$$K = \frac{l_1}{l_2} = \frac{25}{20} = 1.25$$

The volumetric shrinkage is proportional to the cube root of the ratio between the volume of the briquetted blank and that of the sintered part. The shrinkage coefficients depend on the density of the briquetted blank. Shrinkage decreases as the density increases. The amount of bonding metal used has a great effect on the density of the blanks. Thus, for example, if the density of a blank composed of 94 per cent WC and 6 per cent Co is equal to 8.0 g/cm^3, the density of a blank briquetted under the same conditions, but composed of 80 per cent WC and 20 per cent Co, will be equal to 6.8 g/cm^3. This is explained by the fact that the density of tungsten carbide is higher than that of cobalt. Therefore, an increase in the content of the bonding metal reduces the density of briquetted blanks, whereas the shrinkage values, and consequently, the coefficient of shrinkage are increased accordingly.

The density of blanks largely depends on the granularity of the powders being compressed. The density decreases as the grain size becomes finer, and, vice versa, it tends to increase as the grain size becomes coarser. This is explained by the fact that when compressing fine-grained powders the total volume of pores between the grains is larger than when compressing medium- and coarse-grained powders. If, for instance, a blank is composed of 94 per cent of fine-grained tungsten carbide and 6 per cent of cobalt, its density will be equal to 7.2 g/cm^3, whereas a blank of the same composition, but based on tungsten carbide of a medium grain size, will have a density of 8.0 g/cm^3.

The shape of blanks exercises the main influence on the uniform distribution of density throughout the entire volume of a blank. According to the shape of blanks, sintered carbide parts may be subdivided into processable and non-processable ones. The most processable are parts of simple configuration, such as rectangular plates, cylinders, and bushings

with fixed ratios of dimensions. When briquetting such parts, the pressure from the press-mould punch is transmitted equally over the entire cross-sectional area and somewhat decreases as the height becomes greater. The density of such blanks is almost uniform throughout the entire volume. In sintering, they will shrink uniformly.

The most favourable height-to-width (diameter) ratio of a blank being pressed is 1:1. Sometimes, however, this ratio can be up to 3:1.

Non-processable articles are those that have different cross sections with sharp transitions over the briquetting

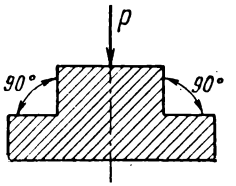


Fig. 6.10. Non-processable part having different cross sections

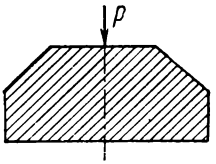


Fig. 6.11. A part with different cross sections but better processability

height. An example of such a part is the blank shown in Fig. 6.10, which is composed of two rectangles of various cross sections. If, however, the shape of this article were changed to a combination of a trapezoid and a rectangle, as is shown in Fig. 6.11, such a part would be easier to compress from the standpoint of distribution of porosity throughout the volume of the part.

In briquetting, a considerably higher density will develop in the places of sharp transitions from one section to another than in all the other sections of the part. When sintering, different degrees of shrinkage in various parts of the part can result in the formation of cracks. Consequently, the shapes of parts and their dimensions determine the possibility of obtaining uniform density in the process of briquetting parts in steel press moulds, as well as the possibility of their manufacture in general.

Systematic improvement in briquetting techniques has resulted in the possibility of manufacturing parts of very intricate shape

Numerous factors affect the density of briquetted parts; therefore, it is necessary to bear in mind that even in one and the same blank and within an entire batch of blanks the density will vary, as a result of which the degree of shrinkage will also vary. It has been established in practice that shrinkage varies within the range of ± 1 per cent. This means that if the shrinkage coefficient for a briquetted blank, as a whole, is equal, for instance, to 1.23, the actual shrinkage coefficient for different sections will vary from 1.22 to 1.24.

When working out new types of parts from hard alloys, it is necessary to take into account the possibilities of their manufacture. Parts should have such shapes and dimensions that they can be manufactured by existing techniques. As has been pointed out above, the main factor influencing the processability of a part is the possibility of obtaining a sufficiently uniform density throughout its entire volume. The shape and dimensions of a blank should approach those of the finished part. These problems are solved jointly by design and process engineers.

Plasticized or sintered blanks are subjected to final treatment, such as abrasive or diamond grinding, electrical, ultrasonic, electrochemical, or other types of finishing. Accordingly, the briquetted parts should have an allowance for final treatment. Taking into account that the treatment of completely sintered parts is a very labour-consuming process, it is necessary to provide the minimum machining allowance possible. Depending on the shape and dimensions of a part, the machining allowance is calculated and specified approximately within the range of 0.1 to 2 mm.

The tolerance in dimensions for manufactured parts is defined according to the process possibilities of their manufacture. Tolerances for manufactured parts depend on a number of process factors, the principal ones being variations in the shrinkage coefficient of a single blank or within an entire batch of blanks, and possible distortion in the shape of a part in the process of its sintering. As has been noted above, variations in the shrinkage coefficient depend on the non-uniform density of a part, which results in distortion of its shape. Moreover, the distortion may be caused by non-uniform heating of the parts in sintering and

by some other factors. The manufacturing tolerance for parts is mainly determined by their shape and dimensions.

Frequently, in mass production of parts, the tolerance is determined experimentally on test specimens selected from various batches of mixtures. The tolerances should be reduced through improvements in the technological process for manufacturing parts. Hence, the dimensions of sintered parts are equal to the dimensions of the finished parts plus the machining allowance and the manufacturing tolerance. The manufacturing tolerance may have either the plus sign (+), or minus sign (—), or both signs (±). The sign of a tolerance is determined in accordance with the purpose of the part. The dimensions of parts may vary within the specified tolerance.

Example 1. After the final machining, the width of a rectangular plate should be equal to 30 mm. The machining allowance is +0.5 mm; and the manufacturing tolerance, ±0.2 mm. Determine the width of the sintered plate.

The width of the sintered plate A will be equal to

$$A = (30 + 0.5 + 0.2) \pm 0.2 = 30.7 \pm 0.2$$

i.e., the width of the part may vary within the range of 30.5 to 30.9 mm.

Example 2. Determine the width of the sintered plate on condition that its machining allowance is +0.5 mm, and its manufacturing tolerance minus 0.4 mm. In this case, the width of the sintered plate will be equal to

$$A = (30 + 0.5 + 0.4) - 0.4 = 30.9 - 0.4$$

i.e., the width of the part may vary within the range of 30.5 to 30.9 mm.

Sintered metal carbide parts may be subdivided according to their shape into two main types: flat and round. Therefore, briquetting press moulds are subdivided according to their design into two types: those for briquetting flat articles (plates for metal-cutting, drilling, and other tools), and those for briquetting round parts (draw plates, dies, stamps, bushes, etc.). To compress flat articles there are

employed flat multi-socket and single-socket press moulds, one of which is represented in Fig. 6.12.

The multi-socket press moulds are usually employed for simultaneously briquetting a number of parts, the briquetting being effected 'edgewise', i.e., the briquetting pressure is applied to the narrow side of the part being compressed. This briquetting method guarantees a more uniform

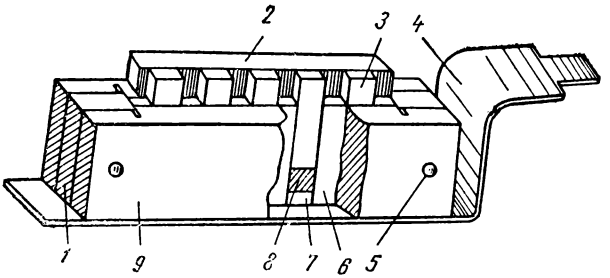


Fig. 6.12. Press mould for briquetting flat pieces
1 — slide block; *2* — limiter; *3* — punch; *4*—support; *5*—pin; *6*—intermediate insert; *7*— pad; *8* — plate being briquetted; *9* — press-mould jaw

distribution of the briquetting pressure and, hence, of density. When pressing on the wide side, i.e., "flatwise", the width of the press mould increases, which makes the uniform distribution of a thin layer of powder in the small cavity of the press mould more difficult.

Press moulds for briquetting flat articles consist of the following main parts: jaws, pads, punches, chamfered inserts, prismatic inserts, slide blocks, and pins. In such a press mould the briquetting operation is conducted in the following manner: the press mould is placed edgewise, and a previously weighed portion of the mixture is poured into each socket. After levelling off the mixture, punches are put into the sockets, limiting plates are placed on the jaws, whereupon the briquetting operation is effected.

The overall dimensions of a press mould depend on the number of parts that are simultaneously briquetted, and on their sizes. The maximum length of the press mould may be within the range of 200 to 300 mm. The press-mould height is equal to the thickness of a pad plus three times

the height of the part being briquetted, and may vary within the range of 35 to 110 mm.

Press moulds for briquetting round parts (Figs. 6.13, 6.14) consist of the following main parts: a sleeve, a punch, a rod, a pad, an intermediate (upper) ring, and a limiter.

The overall dimensions of a round press mould depend on the dimensions of the part being briquetted.

Briquetting in a round press mould is conducted in the following sequence: a previously weighed portion of the

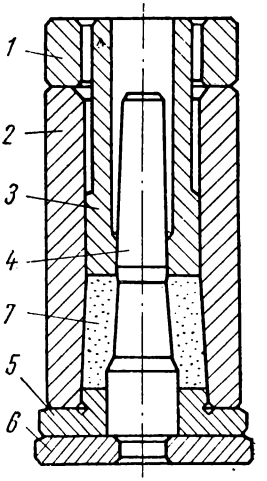


Fig. 6.13. Press mould for briquetting round parts

1 — upper ring; *2* — sleeve; *3* — punch; *4* — rod; *5* — bottom ring; *6* — pad; *7* — powder

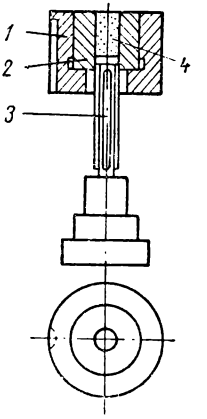


Fig. 6.14. Press mould for briquetting on automatic presses

1 — sleeve; *2* — die; *3* — punch; *4* — powder to be compressed

powder mixture is poured into the sleeve of the press mould and levelled off. Then a punch is inserted, a limiting ring is placed, the press mould is put under the press plunger, and the pressing is effected to the limit. Then the press mould is removed from the press, the limiting ring is taken off, and the rod is extracted together with the pad. The briquetted article is pushed out from the sleeve together with the intermediate ring and punch. The intermediate ring is taken away from the article after it has been pressed

out. The internal diameter of the sleeve defines the external diameter of the article being briquetted. The height of the sleeve should be 2.5 to 3 times greater than the height of the part being briquetted. In the lower part of the sleeve there is provided a conical portion which enables parts of a regular cylindrical shape to be obtained after sintering, and facilitates pushing out the briquetted blank. The basis for calculation of a press mould are the dimensions of the briquetted blanks, that are obtained by multiplying all the linear dimensions of the sintered part by the shrinkage coefficient. Different grades of alloys have different shrinkage coefficients, ranging from 1.18 to 1.27.

The clearance between the punch and the die should not be large; however, it should not be too small, because it should allow the air contained in the powder being compressed to escape.

6.8. Types of Rejects

In the briquetting process, some of the parts obtained have defects. The following kinds of rejects may occur: cracks, exfoliation, faulty compression, contamination, incorrect dimensions, fractures, chipping.

Cracks develop owing to various causes, the principal ones are: high internal stresses induced by high pressures; non-uniform briquetting density in certain portions of a part, resulting from an unfavourable relation between the dimensions of the part and complexity of its shape, as well as from distortions; unequal distribution of the powder mixture in the press-mould socket.

Exfoliation occurs in the sections of very high density and results from the application of very high pressures in briquetting, from a high rate of increase in the pressure applied, on account of non-uniform flowing of the powder in the press-mould socket, and also from poor fluidity of the mixture, when the mixture has not been properly prepared for briquetting, when it contains a large amount of petrol vapours (the mixture is said to be 'wet') or raises dust (the mixture is said to be 'overdried').

Faulty compression is obtained when briquetting 'hard' granules on automatic presses, where the press capacity is

inadequate for crushing the granules. Then between the separate granules there will remain free spaces, which after sintering, as a result of shrinkage, will have the form of fractures and blowholes. This type of reject occurs most frequently on chamfers and cutting edges, i.e., in the places that are the most difficult to be uniformly compressed.

To avoid this kind of reject, it is necessary to employ methods of granulating mixtures which give 'soft' granules that are easily crushed when briquetting. Briquetting on presses with vibrators also contributes to eliminating rejects due to faulty compression.

Contamination occurs when various extraneous matter gets into a mixture prior to briquetting it. Contaminations are found on sintered articles in the form of surface swellings and internal blowholes. This type of reject can be eliminated by strictly adhering to the specified manufacturing process and by proper maintenance of the process equipment.

Incorrect dimensions of articles are obtained when the weighed portion deviates from the calculated one, i.e., when it is greater or smaller. To prevent this type of reject, the dimensions of a 'green' part and its mass must be thoroughly controlled in the course of its briquetting.

Broken and chipped off pieces result from the insufficient strength of a briquetted part as well as from careless handling of green parts. Intricately shaped parts having transitions from thick sections to thin ones, as well as sharp edges and angles are the most likely to be broken or chipped off and, thus, require especially careful handling.

Such types of rejects as cracks, exfoliation, broken and chipped off pieces, and partially incorrect dimensions can be found either on briquetted parts or, after the drying and preliminary sintering operations, on parts that are subjected to machining.

All the other types of rejects are detected only after sintering and thus cannot be corrected.

Depending on the type of reject and stage of its detection, waste of hard-alloy mixtures may be subdivided into three kinds: green lump, lump after drying, and lump after preliminary sintering.

REPROCESSING GREEN LUMP REJECTS

Discarded parts called 'lump rejects' are assorted according to the grades of alloys and then reprocessed as they are accumulated. The lumps are rubbed through a metal sieve having a mesh size of about 250μ. The rubbed mixture is freely sifted on a vibrating screen through a sieve having a mesh size from about 180 to 250μ. The mixture thus prepared is compressed on hydraulic and automatic presses into parts of the desired shape. In case of lengthy storing of the green lump rejects, prior to rubbing they should be washed with alcohol or petrol and then dried in a fume cabinet.

REPROCESSING REJECTS AFTER DRYING

The collected rejects are roasted at a temperature of the order of 650 to 700°C in a stream of hydrogen in order to remove the plasticizing agent. On roasting, the rejects are dry ground in drums. After coarsening the ground rejects, a test sample is taken from the batch of rejects for chemical analysis. A batch of rejects, corresponding to the chemical composition of a given mixture grade, is further wet ground. Batches of rejects with chemical compositions that do not correspond to a given mixture grade are reprocessed, adding the lacking components. Examples of such calculations are given in Chapter V. Rejects with the required amount of components added are charged for wet grinding, which is carried out in ball mills according to a schedule that has experimentally been established for each grade of mixture.

REPROCESSING REJECTS AFTER PRELIMINARY SINTERING

Reprocessing of this type of reject is very similar to that of rejects after drying, with the exception that the rejects, without being roasted, are immediately directed for wet grinding.

Besides lump waste from discarded briquetted parts, there is another kind of waste that is formed when machining an article. This waste (dust-type) may also be subdivided into two types: waste in the form of dust formed when machining blanks on grinding machines with the aid of abrasive

wheels; and waste in the form of chips produced when machining plasticized blanks on machine tools. Waste in the form of dust contaminated with abrasive materials, is not reprocessed at plants manufacturing hard alloys, but is directed to a chemical plant for reprocessing.

Waste in the form of chips is reprocessed by the procedure for reprocessing lump rejects that have been dried.

As the cost of reprocessing rejects and waste is high and the loss of expensive raw materials is involved, it is necessary that work on improving the manufacturing processes be continuously carried out and that the worker and foreman should always carefully observe the manufacturing instructions.

In addition to the aforementioned types of rejects and waste, great production losses are caused by inadequate operation of the process equipment and insufficient tightness. A great amount of waste in the form of dust results from spilling the mixture during briquetting, from deburring, and from cleaning the process equipment.

Reduction of losses, good operation of the equipment, advanced manufacturing processes and inspection methods are the means for continuous improvement of the quality of hard alloys and a cut down in their production costs.

CHAPTER VII

Sintering of Parts

7.1. Fundamentals of the Sintering Process

Sintering is the final manufacturing operation in the production of hard alloys. The sintering operation consists in heating parts up to a temperature of 1350 to 1550°C, holding them at this temperature, and cooling them.

The main object of sintering is the consolidation and strengthening of compressed blanks, which should, after this treatment, possess the specified physical and mechanical properties. When sintering briquetted powders, the following processes take place:

(a) increase in the mobility of atoms;
(b) change in the contact surface between particles;
(c) relieving of internal residual stresses;
(d) recrystallization;
(e) change in mechanical properties;
(f) change in the surface of particles;
(g) displacement of particles.

In the process of sintering hard alloys, some amount of liquid phase in the form of molten cobalt is formed in the part being sintered. Cobalt wets the tungsten carbide grains and partially dissolves them with subsequent crystallization on cooling. Therefore, sintering can be defined as the quantitative and qualitative change in the contact between the particles, caused by the mobility of atoms at elevated temperatures.

Sintering is characterized by appreciable consolidation prior to attaining the temperature of the liquid phase, and by rapid, almost complete consolidation after this phase has appeared.

Consolidation prior to the appearance of the liquid phase occurs in the solid phases, and is accompanied by the diffusion of tungsten carbide into cobalt with the formation of

solid solutions. The solubility of tungsten carbide in cobalt amounts to about 10 per cent.

Consolidation after the appearance of the liquid phase may result from the displacement of solid particles under the influence of the liquid surface tension. Moreover, consolidation is facilitated by the process of recrystallization of carbide grains through the medium of liquid or molten cobalt.

In the following sintering stage, the average size of the tungsten carbide grains increases. The rate of growth of the tungsten carbide grains depends on the amount of the liquid phase, which is determined by the cobalt content in the mixture being sintered; therefore, in high-cobalt alloys the average size of tungsten carbide grains will be greater than in low-cobalt alloys.

WC grains dissolve in the liquid owing to the difference in the surface energy between the fine and coarse particles, as well as to the difference in the degree to which their crystal lattices approach the equilibrium state.

The processes occurring when sintering alloys can be described as follows:

1. At a temperature of 200 to 400°C, the plasticizing agents are removed.

2. At a temperature of 400 to 700°C, the oxides of cobalt, iron, and tungsten are reduced.

3. Within the temperature range of 800 to 1100°C, separate carbide grains are welded together at the points of their contact which results in strengthening of the part.

4. At a temperature of 1150 to 1300°C, cobalt-base solid solutions form. This process is accompanied by fairly considerable shrinkage. According to the phase diagram, the diffusive dissolution draws to its completion at point *a*, whereupon the liquid phase appears (Fig. 7.1). The amount of liquid phase increases with time, and approximately at a concentration of 20 per cent WC in the solution (point *b*) all of the cobalt passes over into the composition of the liquid phase.

5. On reaching the melting point of the eutectic composed of cobalt containing tungsten carbide and carbon dissolved in it, the surface tension forces become active. This results in displacement of the carbide grains, i.e., in so-called

'liquid' flow. The process takes place approximately within the temperature range of 1300 to 1400°C, and terminates almost with complete consolidation of the part being sintered.

6. As the temperature increases from 1400 to 1500°C, additional dissolution of tungsten carbide grains in the molten cobalt continues until its content in the liquid phase

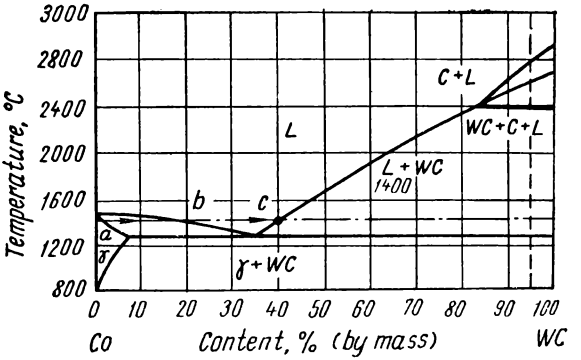


Fig. 7.1. Phase diagram for WC-Co system

reaches a value of about 38 per cent (point *c*). In this temperature range, the carbide phase grains begin to grow, mainly by recrystallization through the liquid phase. In this period, the welding of carbide grains and their dissolution in the molten cobalt reach their maximum. The molten bonding metal fills all the interstices and pores between the carbide grains. If the maximum temperature is maintained for a sufficient period of time, the alloy is completely freed from gases contained in it.

7. After keeping the alloy at the maximum temperature, it is cooled. When cooling from a temperature of 1500 to 1300°C, the tungsten carbide dissolved in the liquid phase precipitates onto the WC grains present which results in an increase both in the carbide grain size and in the contact between them.

With a further reduction in temperature, the carbon which has been dissolved in cobalt is separated out. Free carbon is isolated either in the form of tiny crystalline particles

of graphite or in the form of their conglomerates. Cooling the alloy to room temperature does not essentially affect the structure.

If the specified temperatures and the time during which the temperatures are maintained are carefully observed when carrying out the sintering process, an alloy of a high density can be obtained. Different techniques are used to sinter parts manufactured from mixtures of various granularity. Thus, it is less complicated to sinter parts prepared from coarse- and medium-grained mixtures. Sintering parts manufactured from fine-grained mixtures involves great difficulties.

When sintering fine-grained mixtures, there occurs a very marked shrinkage. As the gases do not have enough time for escaping, closed pores are likely to form. These pores and blowholes are very well identified on the background of the silky uniform structure.

WC-Co alloys may be either two-phase, composed of tungsten carbide grains and bonding metal streaks, or three-phase, when added to the main phases are graphite inclusions or η_1-phase which is a compound of the formula Co_3W_3C, formed by decarbonization of the alloy. In this connection, it is of a very great importance not to allow any variation in the chemical composition of a mixture when preparing the carbides and mixing them with cobalt.

Figure 7.2 shows the characteristic structure of alloys with different grain sizes of the carbide component. Figure 7.3 represents the structure of alloys containing η_1-phase and structurally free graphite.

When sintering WC-TiC-Co alloys, there occur processes that are much more complicated than those occurring when sintering WC-Co alloys. Titanium-tungsten alloys are generally composed of a complex carbide which is a solid solution of tungsten carbide in titanium carbide, tungsten carbide, and cobalt. The complexity of the processes for sintering alloys of this group is explained by their complex composition, although there are no radical variations in the sintering mechanism as compared to that for tungsten-cobalt alloys.

The phase diagram for the WC-TiC-Co alloy system is constructed in the same manner as that for the WC-Co

alloy system, i.e., according to the eutectic type. Sintering is only rendered more complicated by the simultaneous processes of dissolving titanium-tungsten carbide and tungsten carbide in cobalt, their recrystallization through a liquid phase, and more complex formation of the alloy.

It is necessary to note here some peculiar features of the process for sintering the WC-TiC-Co alloy, such as the smaller solubility of the solid phase in the liquid one and

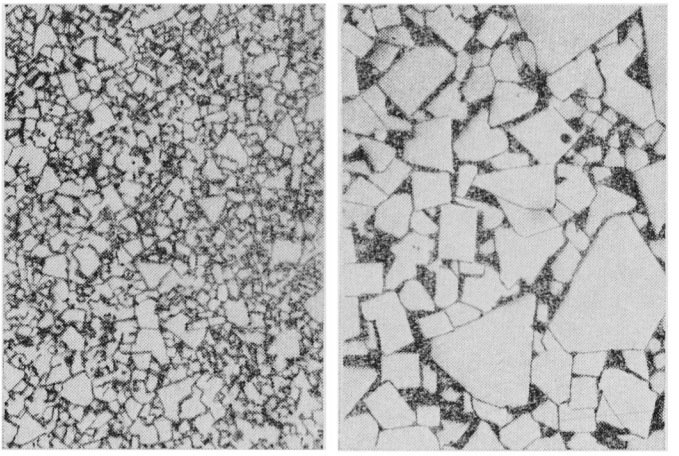


Fig. 7.2. Structure of WC-Co alloys with different grain sizes of carbide phase (1500×)

the lower wettability of the solid solution by molten cobalt. Moreover, it is believed that the presence of a liquid phase in sintering interferes with the growth of TiC-WC grains, and their growth proceeds by a combining recrystallization, i.e., through the growth of some recrystallized grains at the expense of others. The higher the temperature, the faster the rate of this recrystallization.

The structure of titanium-tungsten alloys is characterized by a so-called annular structure in which the colouring of the grains of the titanium phase varies due to the difference in the concentration of the central and peripheral portions

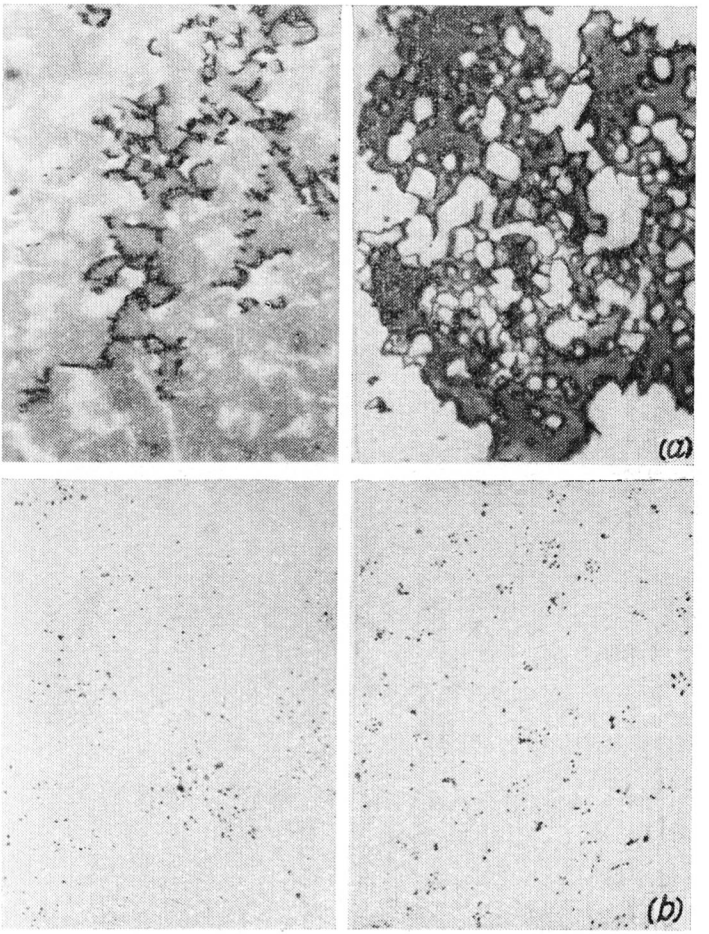


Fig. 7.3. Structure of alloys, containing graphite and η_1-phase
(*a*) alloy containing η_1-phase; (*b*) alloy containing graphite

of the grain, resulting from non-uniform saturation of the titanium carbide grains by tungsten carbide.

The recrystallization of the titanium-tungsten carbide results in the formation of particles of a rounded form, which

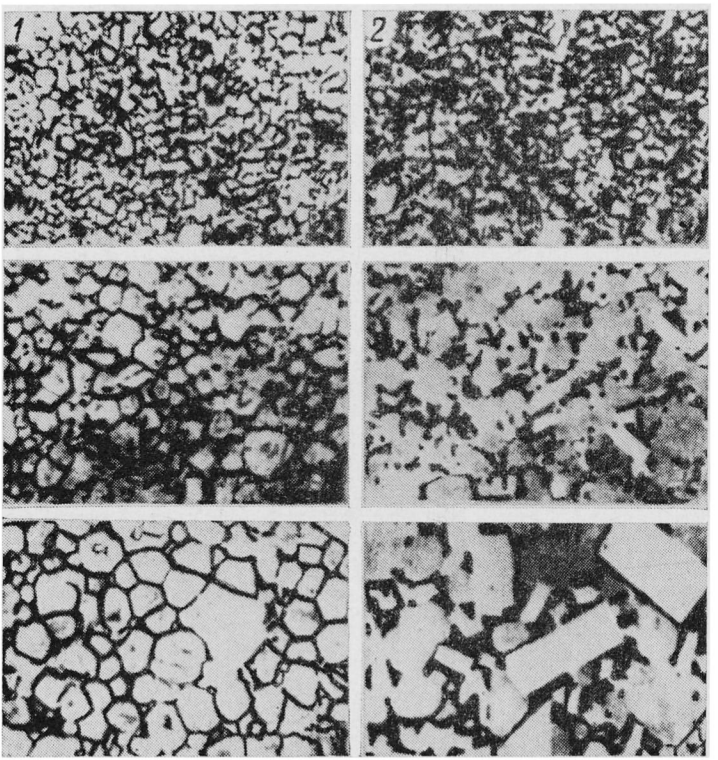


Fig. 7.4. Structure of WC-TiC-Co alloys with various grain sizes of titanium and WC-phases (1500×)
1 — TiC-WC solid solution (titanium phase); *2* — WC-phase

is explained by the high surface tension of the solid solution of tungsten carbide in titanium carbide.

As a result of sintering, the structure of a titanium-tungsten alloy may be one of two types, namely: *two-phase* in the case of a high-titanium alloy, composed of grains of a solid

solution of tungsten carbide in titanium carbide and the cobalt phase; and *three-phase*, where in addition to the aforesaid phases, there is also present a second carbide phase composed of tungsten carbide grains.

This type of structure is characteristic of alloys having a low content of titanium (up to 12 to 13 per cent). In addition to these phases, two- and three-phase alloys may contain optional phases, depending on the sintering conditions; these are structurally free graphite in the case of carbonization of the alloy, or η_1-phase in case of decarbonization. Cases of decarbonization occur very rarely when sintering WC-TiC-Co alloys. There are more frequently encountered alloys with graphite, the content of which usually ranges from 0.2 to 0.5 per cent by volume and sometimes from 1 to 1.5 per cent by volume.

Figure 7.4 shows the structure of a titanium-tungsten alloy.

7.2. Granularity of Carbide Phases

The average grain size of carbide phases increases considerably after sintering as compared with the grain size of the starting carbide powders. Depending on the grain size of the carbide phases, alloys may be subdivided into extra fine-grained, fine-grained, medium-grained, coarse-grained, and very coarse-grained (Table 7.1).

Table 7.1

Characteristics of Tungsten-Cobalt Alloys According to the Sizes of the Main Mass of Carbide Phase

Alloy	Sizes of the main mass of grains of carbide phase, μ	Minimum content of the main mass of grains of carbide phase, vol., per cent
Extra fine-grained	< 1 to 1	60
Fine-grained	1	50
Medium-grained	1 to 2	50
Coarse-grained	2 to 5	50
Very coarse-grained	6 to 15	50

One of the main reasons for an increase in the grain size consists in recrystallization through the liquid phase. However, there are also other factors affecting the grain size of an alloy. One of them is the granularity of the starting mixture. The coarser the starting mixture, the greater the average size of the carbide phase grain. The growth of grains of WC-phase depends on the carbon content in the mixture being sintered. An increased carbon content in the starting carbide results in a faster rate of growth of tungsten carbide grains. If the carbon content is insufficient, the structure of the alloys is fine-grained. In low-carbon alloys, part of the cobalt is bound in η_1-phase, as a result of which, the amount of the liquid phase decreases and the growth of grains slows down. An increase in the amount of the liquid phase improves the recrystallization conditions, which in turn, contributes to grain growth.

Consequently, under certain conditions, high-cobalt alloys will possess a relatively coarse-grained structure.

The presence of small amounts of other carbides in the mixture being sintered exercises a considerable influence on the growth of the carbide phase grains in WC-Co alloys. Additions inhibiting the growth of grains of WC-phase include, first of all, the carbides of vanadium, chromium, tantalum, and niobium. The most effective addition is vanadium carbide which in slight amounts (0.25 per cent), even at relatively high sintering temperatures (up to 1550°C), produces extra fine-grained alloys having a grain size of the main mass of grains of WC-phase up to 1 μ. The effect of vanadium carbide increases with its content.

In practice, industrial grades of alloys are obtained by adding carbides to them with a view to controlling the grain size of the carbide phase. At present there is not as yet an adequate explanation of the mechanism of the influence of the additions on the grain size of WC-phase.

When sintering titanium-tungsten alloys, the size of grains of the carbide phase depends on the degree of coalescence of grains and their recrystallization through the liquid phase. However, in this case, in contrast to the case of sintering tungsten-cobalt alloys, it is possible to consider the recrystallization process as being of less importance.

In the alloys of the titanium group, there are observed some peculiar features in the growth of grains of both carbide phases (TiC-WC and WC). One carbide phase interferes with the growth of the other. The growth of grains of TiC-WC solid solution is rendered especially difficult in the presence of fine grains of tungsten carbide. This may be explained by the fact that tungsten carbide grains mechanically divide the grains of titanium-tungsten carbide and, thus, interfere with their growth owing to combining recrystallization. The grains of TiC-WC phase have a less pronounced influence on the size of grains of WC-phase. In TiC-WC-Co alloys, the finer the average size of the carbide grains, the finer the grain obtained by sintering the alloy. In these alloys, however, the grain size of the starting mixture exercises a smaller influence than in the case of WC-Co alloys. Therefore, almost all titanium-tungsten alloys may be related to the group of medium-grained alloys having a grain size of the matrix within the range of 1 to 2 μ.

In titanium-tungsten alloys, the influence of alloying additions, such as tantalum carbide and niobium carbide, on the growth of grains of carbide phases is also insignificant. The use of alloying additions in these alloys is limited.

The growth of grains of the carbide phases is affected by process factors, such as the sintering temperature, and the time the maximum sintering temperature is maintained. It has been observed in practice that an increase in the sintering temperature and duration contribute to the growth of the grains of carbide phases. Under these conditions, a significant change in the grain size can be observed even with relatively small temperature variations for TiC-WC-Co alloys and for WC-Co alloys having but a relatively small content of the cobalt phase, say, about 6 per cent by mass. In this case, the growth of the grains of carbide phases occurs due to an increase in the amount of liquid contributing to more intense recrystallization as well as owing to an increase in the contact surface because of the welding together of grains.

The time during which the sintering temperature is maintained influences the grain growth in the same manner as the value of the sintering temperature, but to a smaller extent.

The most uniform alloys, as regards the grain size, are obtained by using a starting carbide powder of uniform granularity provided that the conditions of crystal formation approach the equilibrium conditions.

The grain size of the carbide phase can be adjusted by varying the sintering schedules and granularity of the tungsten carbide powder. This is effected through the medium of various carbide-formation schedules, or by varying the duration of grinding.

The cobalt phase grain size considerably exceeds that of the carbide grains, although during metallographic examination, the cobalt phase appears as thin layers surrounding the carbide grains. It is supposed that the grains of the bonding metal represent dendritic formations accommodating between their branches tungsten carbide grains. Investigation of the relation existing between the grain size and the process factors and alloy composition has shown that the cobalt grain size is independent of the sintering temperature. The greater the cobalt content in WC-Co alloy, the greater cobalt phase grain size. For titanium alloys, substituting a complex TiC-WC carbide for a part of WC results in the growth of the cobalt phase grain size.

When establishing the process schedules of sintering, it is necessary to take into consideration the peculiar features of the structure of the given alloy and the influence of various factors on its granularity. Therefore, the sintering temperature, holding time, and other parameters will have to be selected with due regard to requirements to be met by the structure and properties of the alloy of a given grade.

7.3. Influence of the Sintering Atmosphere on the Composition of an Alloy

One of the main objects of the sintering operation is to preserve the specified composition of an alloy, particularly its carbon content; for a decrease in the carbon content results in a marked decrease of its mechanical strength. Oxidation of the alloy components should also be prevented; for this purpose the sintering operation should be conducted in a protective atmosphere, which does not contain oxygen or moisture. Hydrogen or carbon monoxide are commonly

employed as the protective gas atmosphere. The atmosphere is created by passing a hydrogen stream through a furnace.

Cleaning hydrogen from moisture and oxygen sharply reduces the degree of decarbonization. Taking this into account when sintering parts, the hydrogen employed must be dried to the dew point (— 45 to — 50°C), i.e., have a moisture content of not more than 0.07 g/cm^3, and be freed from oxygen to a content of the latter of not higher than $3 \cdot 10^{-4}$ per cent.

However, even under these conditions, hydrogen is capable of causing decarbonization of mixtures of tungsten carbide and cobalt. Consequently, even after complete purification of hydrogen, when sintering hard alloys, the hydrogen must be carbonized to some extent. To prevent strong decarbonization of sintered parts, the hydrogen used should be as dry as possible and should contain a minimum amount of oxygen, and special filling agents should be employed. The use of high-carbon carbides provides an additional protection against the decarbonizing effect of hydrogen.

The degree of decarbonization also depends on the dispersity of the mixture. The finer the mixture powder, the greater the carbon content in the mixture required to reduce decarbonization.

Various filling materials are employed in order to protect the parts being sintered from decarbonization. The filling composition is selected so as to create a favourable gas atmosphere around the part. The effect of the filling agent is based on the combination of the carbon contained in it with the hydrogen and oxygen present in the furnace chamber to form hydrocarbons or carbon monoxide that surround the part being sintered. Moreover, the carbon of the filling agent is capable of directly diffusing inside the part, thus carbonizing it. The degree of carbonization will depend on the thickness of the part. Parts of small thickness are much easier to carbonize than thick parts. Thin parts are usually completely carbonized during the sintering operation, and possess a uniform structure from their edges toward the centre.

When sintering parts made of hard-alloy mixtures, the following filling agents are employed: graphite grit, a powder of fused aluminium oxide (so-called electrocorundum or

corrax), and a mixture of corrax with graphite powder, and in some cases with carbon black. Graphite grit creates a more carbonaceous atmosphere than corrax does; that is why in parts that were sintered in graphite grit, graphite inclusions are encountered more frequently.

To avoid this phenomenon, combined fillings of corrax containing various amounts of graphite powder are employed in combination with hydrogen supplied into the furnace during the sintering process.

When sintering tungsten-cobalt alloys, fillings composed either of pure aluminium oxide or of aluminium oxide containing small additions of graphite are used.

For sintering TiC-WC-Co alloys, a filling composed of graphite grit is usually employed.

Practical experience has shown that a filling of a definite composition (the most efficient one) should be selected for each grade of alloy. The filling may be used repeatedly. However, with each subsequent passage of a filling through the furnace, both its composition and properties change. The carbon contained in the filling is likely to disperse under the influence of temperature, which is conducive to an increase in the carbonizing capacity of the filling. To prevent a large amount of carbonization, the fine fraction of graphite is sifted out after each passage of the filling through the furnace. After a certain period of time, the filling should either be replenished or replaced.

Sintering in pure corrax often results in decarbonizing of parts. To obviate the decarbonizing effect, the corrax must be pre-roasted in a furnace.

Although for each grade of alloy, the composition of the filling is predetermined, nevertheless, for guaranteeing the specified composition of the alloy being sintered, a given type of filling should be previously tested by using it to sinter test specimens of parts of a particular batch, followed by evaluating their structure and properties.

The most complicated problem of the sintering operation resides in preserving a given carbon balance in the parts being sintered.

A method has been proposed by which the required content of carbon can be preserved in an alloy; this method is based on the combined effect of hydrogen supplied into

the furnace and the carbon contained in the filling used. As is known, parts are decarbonized to the highest extent at a temperature of 1160°C. Therefore, if intermediate sintering at a temperature of 1100 to 1200°C in a carbonizing medium (graphite) is conducted prior to the final sintering, it is possible to obtain, after the final sintering, a composition of an alloy having the required carbon content. However, the purpose of the filling is not limited to creating a suitable gas atmosphere. The filling serves also to transmit heat from the walls of the boat to the parts being sintered. The fillings, which are essentially non-sinterable powders, possess poor heat conduction; therefore, on being heated, they are capable of retaining the heat. When sintering parts in graphite grit, the parts are more intensely heated than they are in corrax, because the coefficient of heat conduction of graphite grit is almost twice that of corrax.

The heat conduction of corrax fillings containing additions of graphite grit lies within the range between that of corrax and that of graphite, and increases as the graphite content grows.

The heat conduction of the briquetted parts appreciably exceeds that of the fillings. The coefficient of heat conduction of alloys increases with the temperature. Alloys of various chemical compositions differ in their heat conduction. A considerable difference in the coefficients of heat conduction of WC-Co and TiC-WC-Co alloys is observed, even when the cobalt content is the same.

The filling also plays an insulating role, inasmuch as it separates one part from another and prevents them from sticking to each other during the sintering operation.

Consequently, fillings are given great attention in the production of sintered metal carbides. There exist special rules to be followed when manufacturing them.

It is common practice to prepare a graphite filling from graphite grit having a particle size within the range of 1 to 3 mm.

To prepare a filling from aluminium oxide (corrax) containing additions of graphite powder, the powders are intermixed (for a period of 1 to 2 hours) in ball mills, using steel balls or nails to improve the distribution of graphite in the corrax powder. For fillings of this type use is made

of graphite powder sifted through sieves with a mesh of 09 and 045.

Uniform distribution of graphite in a corrax filling is an indispensable condition to be observed when preparing a filling, since it determines the uniformity of products being sintered. Prior to use, the graphite and corrax fillings must be roasted at a temperature of 1500 to 1550°C with a view to removing moisture and impurities from them.

A filling should meet the following requirements:

1. The filling material should not enter into direct chemical reaction with the parts being sintered to form new compounds.
2. The filling material should be relatively cheap.
3. The filling should be capable of preserving its loose nature after heating it to a high temperature.
4. The filling should be capable of being used repeatedly.

7.4. Influence of Sintering Conditions on the Properties of an Alloy

The properties of a hard alloy are essentially affected by the sintering conditions: the sintering temperature, the period of time the parts are kept in the furnace, the cooling and heating schedules, the mass of the parts loaded into a boat and their arrangement in it, the nonuniformity of the composition and dispersity of the filling, and a number of other factors.

The influence of sintering conditions on the properties of grade T15K6 alloy has been investigated. The investigations have shown that an increase in the rate of motion of the boats results in a corresponding increase in the values of coercive force and density, but in a reduction in the bending strength.

When using a standard sintering schedule, an increase in the total mass of the parts loaded into a boat led to lowering of their strength.

The arrangement of specimens along the height, width, and length of the boat also affected the properties of the alloy. The specimens in the top layer possessed a higher bending strength, coercive force, and specific electrical resistance. The specimens of the outside rows of all the

layers in the boat possessed increased bending strength and coercive force. Moreover, there was noted an increase in the coercive force of the specimens at the beginning and at the end of each row in a boat, irrespective of the layer height.

A practical conclusion can be drawn from these investigations, namely, when sintering parts of various thickness there should be employed different rates of motion of the boats in the furnace. The temperature curve of the furnace should be stretched out, with equal zones of rising and lowering of temperature.

7.5. Sintering Procedure

Parts are sintered in one or two stages in electric furnaces provided with an alundum or graphite tube, as well as in vacuum furnaces. In two-stage sintering, the presintering operation is effected at a low temperature in the front part of the tube or in a separate furnace. The plasticizing agent is removed in the first sintering stage, and the alloy is formed at elevated temperatures in the second stage.

The presintering schedule is selected with due regard to the purpose of this operation, the shape and overall dimensions of the part being sintered.

The maximum temperature of the final sintering operation mainly depends on the composition of the alloy. For WC-Co alloys it depends on the cobalt content and the granularity of the mixture from which the parts are manufactured. The higher the cobalt content or the higher the dispersity of a mixture, the lower the sintering temperature. For TiC-WC-Co alloys, the sintering temperature depends on the contents of titanium and cobalt. Given below are average temperatures for sintering alloys, depending on the composition and granularity of the starting mixtures, °C.

Alloy containing 6 per cent Co

Fine-grained	1400
Medium-grained	1430
Coarse-grained	1450
Very coarse-grained	1480

Alloy containing 8 per cent Co

Fine-grained	1400
Medium-grained	1450

Coarse-grained	1480
Very coarse-grained	1500

Alloy containing 10 per cent Co

Fine-grained	1400
Medium-grained	1420
Coarse-grained	1450
Very coarse-grained	1450

Alloy containing 20 per cent Co

Fine-grained	1380
Medium-grained	1380
Coarse-grained	1380
Very coarse-grained	1450

In practice, it is permitted to deviate from the aforecited temperature schedules. However, when sintering at lower temperatures, the duration of the process is increased. The application of elevated temperatures reduces the duration of the process, but rapid changes in temperature may result in cracking of parts of complicated shape. To enable the processes of consolidation of the alloy and grain growth to be carried out to the full extent, the parts must be kept for a certain period of time in the hot zone of the furnace.

The hot zone is the section of the tube or muffle of the furnace, which has the maximum temperature. The length of hot zones for furnaces of various types is equal to 250 to 450 mm. The rate of travel of the boats in the furnace is calculated depending on the length of the hot zone. The time the boats are kept in the hot zone varies from 30 minutes to 2 hours. The main characteristic of each sintering furnace is the temperature curve showing the temperature at each point of the tube. Therefore, prior to starting sintering of the parts, it is necessary to take off the temperature curve of the furnace. It is taken off in a furnace which has been heated up to the sintering temperature. The temperature in the first section of the furnace (with a temperature varying from about 200 to 700°C) is measured by means of a chromel-alumel thermocouple which is moved into the furnace at a very slow speed, say, by 10 cm in each period of 10 to 15 minutes.

The steady temperature of this section of the tube and the distance of the end of the thermocouple from the begin-

ning of the charging sleeve of the furnace are fixed. Then the temperature curve of the next section of the furnace (with a higher temperature) is taken off by means of a special 'temperature' boat which is an ordinary graphite boat having a graphite pipe (screen) placed in it on a layer

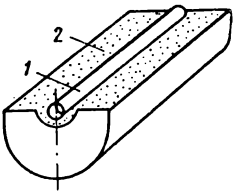


Fig. 7.5. Schematic drawing of a 'temperature' boat for plotting a temperature curve
1 — 'temperature, pipe; *2* — filling

of filling, the pipe being provided with a bottom in its central portion. Figure 7.5 represents a schematic drawing of this boat.

The temperature boat is placed in the furnace and moved along the furnace by means of a mechanical pusher at a rate of about 5 to 7 mm per minute. Prior to starting the pusher, the exact time and place of charging the temperature boat are fixed. Behind the temperature boat, move boats filled with rejected parts that are placed in a suitable filling. As the temperature boat approaches the hot zone of the furnace, the temperature pipe is heated and in time intervals of 10 to 15 minutes the temperature is measured by means of an optical pyrometer. When the boat moves in the hot zone, the temperature is measured every 5 minutes. All the temperatures and time intervals at which they are measured are recorded. After that a pipe length *vs* temperature curve is plotted, i.e., a graph showing the distribution of temperatures along the length of the furnace tube. Figure 7.6 represents a temperature curve characteristic of sintering furnaces.

The temperature curve can be plotted, not only with the aid of a temperature boat, but also by means of a so-called 'creeping' tungsten-rhenium thermocouple built into

the boat. This method is more accurate, but it is much more complicated as concerns assembly of the boat.

In resistance furnaces provided with an alundum tube, the parts are sintered in graphite boats of round or rectangular cross section depending on the cross section of the tube or muffle. Put on the bottom of the graphite boat, approximately to a height of 15 to 20 mm, is the filling on which

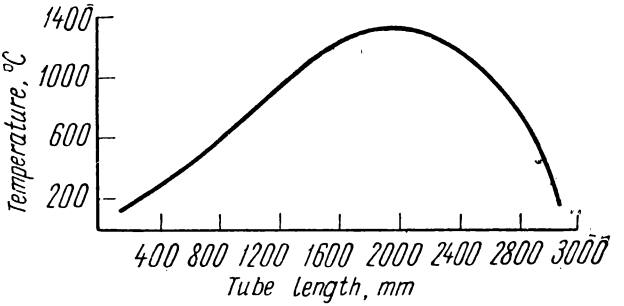


Fig. 7.6. Temperature curve of sintering furnaces of modern design

are placed briquetted parts on their bearing edge with the working part upward or on the flat surface.

The parts are covered with a filling layer 3 to 5 mm thick. Placed on this layer is the subsequent row of parts and so on, until the entire boat is filled up. The upper row of parts is covered with a filling layer up to 10 mm thick, and in some cases they are covered with a graphite plate.

Parts, the surfaces of which must meet special requirements, as well as thin and very long parts that are likely to buckle during the sintering operation, are placed on graphite plates that, in their turn, are covered either with a thin layer of filling or with paper. Further, the parts are covered with a filling layer, on which is again placed a plate with parts, such packing being continued until the entire boat is filled.

Recently the assortment of sintered carbide parts has been appreciably increased. Now there are manufactured various types of shaped tools of intricate form, as well as thin and long plates that are employed as knives for centreless grinding machines 400 × 15 × 5 mm in size, and as plates

up to 250 × 15 × 2 mm in size for various wood-working tools.

The manufacture of long and thin plates is complicated because they must be strictly rectilinear. This is essential as they must be accurately fitted to the polished support of tools. To this effect, it is necessary to polish the bearing surfaces of sintered carbide plates, which offers difficulties

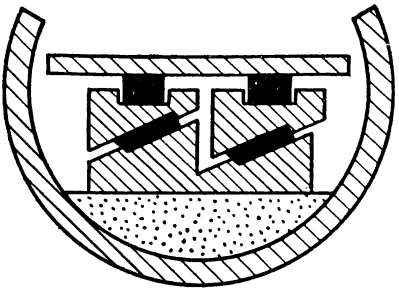


Fig. 7.7. Schematic drawing showing packing of graphite box in a boat

when there is a great curvature. Because of this, it is desirable to obtain a sintered part having a minimum value of buckling.

Figure 7.7 schematically represents packing, guaranteeing minimum buckling of parts.

Under the effect of a load, the top plate presses on the plate being sintered, from above and from the ends, thus preventing buckling of the plate in any plane.

To avoid carbonization of a part, a thin layer of corrax is put on the well-polished surface of a graphite plate. Corrax is also put on the cemented carbide plate under the top graphite cover plate. If the shape of the piece is very complicated and does not allow contacting with the filling, the part is placed on a graphite plate; then supports are placed, the height of which is somewhat greater than that of the part, and a second plate is placed on the supports. All the free space of the boat is filled up with the filling material.

There are also possible other packing methods. The boats with the parts are placed into the furnace from the side of the charging sleeve. A mechanical pusher is actuated,

and the boat begins to move along the furnace at a fixed rate.

After sintering, the parts are discharged from the boats on a sieve having apertures of 7 to 8 mm in size, in order to separate them from the filling material. The parts are finally cleaned on a special apparatus with the aid of either moistened sand or metallic crumbs that are supplied by compressed air.

Parts that are briquetted as blanks and require complicated machining, as well as shaped parts, are presintered in resistance furnaces provided with a graphite or alundum tube or muffle, in a continuous hydrogen stream at a temperature of 700 to 750°C.

The order of packing parts for presintering and that of charging the boats into the furnace are similar to those described above.

A chromel-alumel thermocouple is employed for measuring the presintering temperature, which is recorded by a recording instrument.

The final sintering temperature is automatically controlled. The automatic control instruments are adjusted to the hot zone of the tube. The temperature is additionally controlled by an optical pyrometer.

7.6. Equipment Used for Sintering Parts in Hydrogen

The presintering and final sintering operations are effected in resistance furnaces provided with an alundum tube, a muffle, or a graphite tube. Moreover, vacuum furnaces are also used for sintering.

In the resistance furnaces with an alundum tube or muffle, a molybdenum wire is used as the heating element (Fig. 7.8). At one side of the furnace there is provided a charging sleeve in the form of a tube or muffle. At the other end there is also provided a sleeve with double walls, inside which cold water is continuously circulating. This sleeve is called a cooler. At the inlet of the cooler the temperature of the water should be 20 to 25°C. The temperature of the water flowing out of the cooler should not exceed 40°C.

The alundum tube or muffle is placed on a layer of a heat-sulating fillin g (usually corrax). Heat-insulating bricks

are placed on the corrax. A furnace with a molybdenum winding can operate only in a protective gas atmosphere, as molybdenum is capable of easily oxidizing on heating, and of forming carbides. That is why a small amount of hydrogen is supplied inside the metal housing accommodating the furnace.

A rotameter is used to measure the quantity of hydrogen passing through the furnace.

It is the best practice to operate the furnaces of this type continuously and under constant conditions, because frequent switching on and switching off, as well as switching-over from one operating duty to another, result in burning

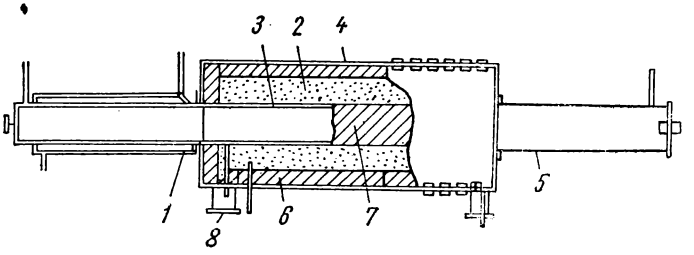


Fig. 7.8. Schematic drawing of furnace equipped with a molybdenum heater

1 — cooler; *2* — heat-insulating filling; *3* — alundum muffle; *4* — iron housing; *5* — charging part of the furnace; *6* — heat-insulating brick; *7* — molybdenum heater; *8* — furnace uprights

of the molybdenum winding and in the furnace getting out of order.

The furnace may be supplied either directly from power mains or through a transformer.

At present, furnaces with molybdenum heating elements are considered to be the best. They are very reliable in operation and easily regulated; their deviations from a prescribed temperature schedule are insignificant, which allows almost a constant temperature to be maintained during the entire sintering period. In the furnace space there are no substances resulting from the reaction between the material of the tube or muffle and the gas medium, which makes it possible to control the composition of the latter. Owing to this, parts sintered in a furnace with an alundum

tube or muffle, possess a structure and properties that are more stable than those of parts that are sintered in furnaces with a graphite tube.

The high stability of the tubes and the simplicity of assembling furnaces with a molybdenum heating element render their application more advantageous also from the economical point of view.

The design of the resistance furnace with a graphite tube, is similar to that of the furnace with an alundum tube, with the exception that the tube itself serves as the heater; the tube is heated by electric current supplied to both its ends (Fig. 7.9).

The furnace is heated by means of 10 to 20 V, 2300 A a.c. supply.

The furnace temperature can be controlled by varying the current. Electric current is supplied to the tube through the medium of a special head and a graphite cone fixed in it, which improves the contact and eliminates current losses.

Current-conducting heads in the furnace housing are made of iron or bronze. To obviate any deformation of the heads under the effect of elevated temperatures, they are made hollow to allow cold water to flow through them.

Because of this, the ends of the tube close to the cooled heads are heated to a lower temperature as compared with its middle portion.

The graphite tube is placed in an iron housing. The space between the walls of the housing and the tube is filled with a layer of graphite grit or roasted soot, in order to improve the heat insulation. A furnace of this type, like the furnace equipped with an alundum tube, is provided with charging and water-cooled discharging sleeves. A rotameter is used to control the supply of hydrogen into the furnace.

A serious disadvantage of the furnace of the given design is that it does not maintain a steady temperature, which is explained by variation in the voltage in the power mains and by the change in the tube resistance, caused by the carbon gradually burning out.

Moreover, the composition of the gas medium in the furnace space constantly changes on account of the burning of the tube carbon, and its reaction with hydrogen and the

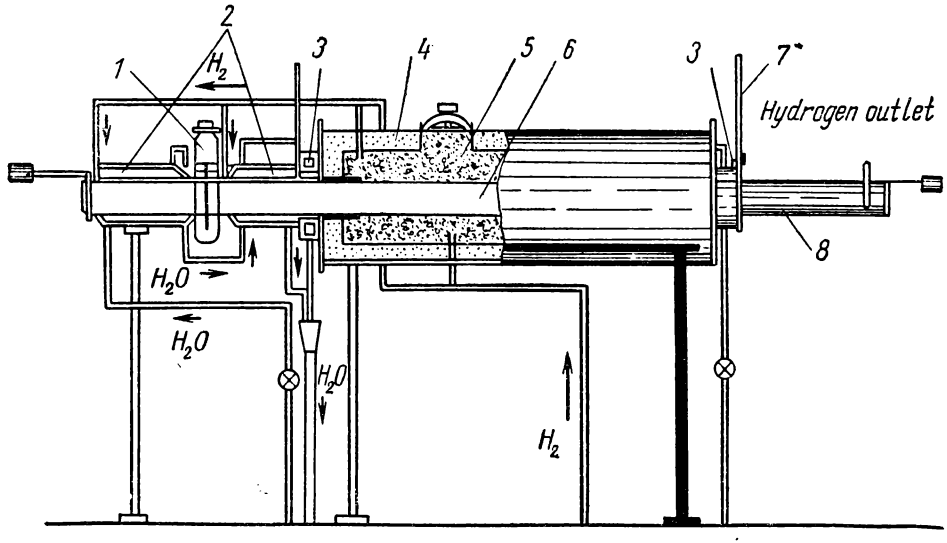


Fig. 7.9. Schematic drawing of an electric resistance furnace equipped with a graphite tube

1 — lock; *2* — coolers; *3* — contact heads; *4* — ceramic insulation; *5* — graphite filling; *6* — graphite tube; *7* — current-supply busbar; *8* — charging sleeve

material being sintered. The low stability of graphite tubes necessitates frequent overhauls of the furnaces and, hence, their frequent shutdowns, because the overhaul of a furnace is a very labour-consuming operation. Dispersed soot is used as the heat-insulating material, which considerably worsens the labour conditions and produces a great deal of dust in the room where the furnaces are overhauled.

In view of the aforementioned disadvantages, furnaces equipped with a graphite tube may be recommended only for effecting presintering at low temperatures.

7.7. Sintering Parts in Vacuum

In addition to sintering parts in a hydrogen medium, they may be sintered in vacuum. When sintering in vacuum, the gases can be completely removed from the parts being sintered, and a high density of the sintered parts can be attained.

Vacuum sintering facilitates consolidation of the parts and a more uniform distribution of the liquid among the carbide particles as a result of better wettability of carbide by the molten cobalt, and of faster shrinkage.

In vacuum sintering it is more difficult to preserve the specified composition of an alloy, as a certain amount of cobalt evaporates under vacuum. Moreover, decarbonization is liable to occur, which results in lowering the bending strength and increasing the hardness and wear resistance.

To preserve the cobalt content in the composition of an alloy, the sintering operation should be conducted at a relatively high residual pressure (several tenths of a millimetre Hg).

To guarantee the normal carbon content, the starting mixture should contain an excess of free carbon equal to 0.2 to 0.5 per cent.

The schedules of sintering in vacuum do not differ in principle from those of sintering in the atmosphere, but when sintering in vacuum lower sintering temperatures may be used.

The vacuum-sintering furnaces operate according to the following typical schedule: evacuation, heating up to the sintering temperature at a rate of 20 to 30 degrees per minute,

holding the parts at the sintering temperature, and cooling. During the sintering operation, the pressure should be maintained at a level of 0.5 to 1.0 mm Hg.

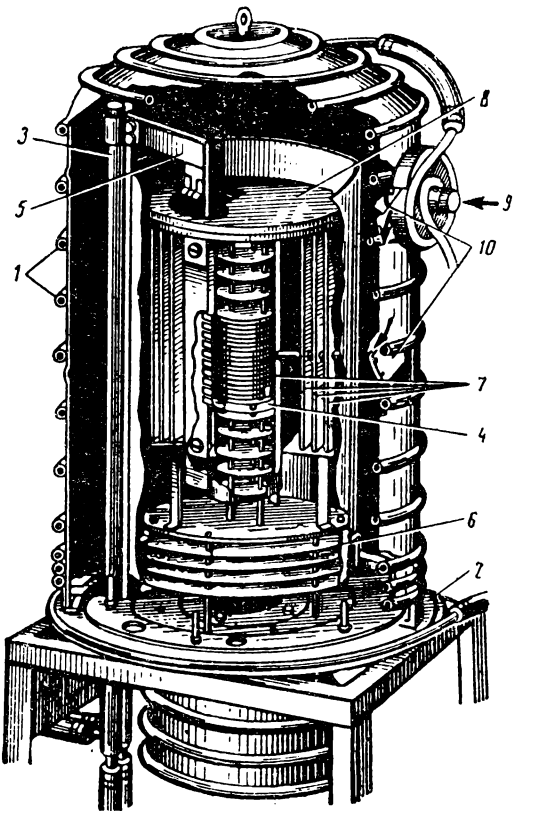


Fig. 7.10. Schematic drawing of a vacuum resistance furnace
1 — coil pipe with running water; *2* — support plate; *3* — copper pipes; *4* — molybdenum heater; *5* — molybdenum busbars; *6* — lower molybdenum screens; *7* external cylindrical screen; *8* — upper molybdenum screens; *9* — sight hole; *10* — mirrors

When using intermittent-duty vacuum furnaces, the process cycle is longer than when sintering in hydrogen; for evacuation and cooling require considerable time. Much more time is spent on placing the parts on a rack and char-

ging them into the furnace; because of this, the productive capacity of modern vacuum furnaces is rather low.

However, parts sintered in vacuum furnaces are characterized by a higher uniformity; therefore, the use of vacuum sintering is fully justified.

To sinter in vacuum there may be employed induction furnaces and rack-type resistance furnaces. Figure 7.10 schematically represents a vacuum furnace.

The vacuum chamber is a steel cylinder cooled by means of running water. The chamber is placed on a support plate with a rubber sealing. Attached from below to the support plate is an inlet branch pipe of a diffusion pump connected to a fore-vacuum pump. Electric current is supplied to copper tubes that are also cooled by water. There is a heater made of strips of sheet molybdenum secured on pipes. The heater is surrounded by molybdenum screens, to reduce heat losses.

In addition to the described design, there are also available other types of vacuum-sintering furnaces.

As regards the process cycle, vacuum furnaces are subdivided into intermittent-duty and continuous furnaces. The productive capacity of the continuous furnaces is much greater than that of the intermittent-duty furnaces.

Prior to the final sintering in the vacuum furnace, the parts are subjected to presintering at a low temperature of the order of 650 to 700°C, packed in a filling consisting of graphite grit. For the final sintering, the parts are placed on a graphite rack with a small layer of corrax filling. The parts are mainly placed on their narrow edge, in order to reduce the surface of contact with the filling material.

The rack is placed into the graphite crucible of the vacuum furnace. After charging the rack, the vacuum furnace is closed with a cover which is then secured with bolts. After sintering, the parts are cleaned in an apparatus with metallic crumbs and submitted to inspection.

7.8. Activation of Sintering

Recently, extensive research work on the activation of sintering has been conducted. By activated sintering is usually meant acceleration of changes in the properties and

density of parts under the influence of such factors as oxidation-reduction reactions; dissociation of oxides, halides and hydrides; as well as cyclic variations in the sintering temperature, effect of magnetic field, ultrasonic oscillations, etc. All these effects contribute to increasing the diffusion activity by increasing the number of defects making this possible.

The simplest example of activated sintering is sintering with the use of oxidation-reduction reactions. There are data available showing that the presence of moisture in the sintering atmosphere activates shrinkage owing to multiple oxidation-reduction reactions taking place due to local supersaturation with water vapours.

Another example of activated sintering is sintering parts in vacuum, where consolidation proceeds at a faster rate.

Utilization of the effect of the heating rate on the sintering process is one of the physical methods of activation. This is possibly connected with the fact that when heating slowly, the defects of crystalline structure are eliminated at low temperatures; therefore, they cannot exercise an influence on the consolidation of the parts. In the case of fast heating, a considerable part of defects is preserved up to elevated temperatures; because of this, their influence on shrinkage becomes more conspicuous. That is why intermediate sintering of alloys at low temperatures is capable, to a considerable extent, of reducing the subsequent consolidation at elevated temperatures.

The addition of various alloying elements may also be considered as activated sintering.

Analysis of the methods of activated sintering permits certain preliminary conclusions to be drawn with regard to conditions for obtaining the best properties of alloys in sintering.

Thus, to obtain a maximum density of parts, it is desirable to use fine-grained powders with a defective surface structure, as well as conditions (schedules) enabling the surface processes to occur at a fast rate, thus increasing the rate of consolidation, levelling out of the surface of the pores, and removal of impurities.

7.9. Types of Rejects in Sintering, Methods of Their Correction, and Reprocessing of Waste

When sintering parts, various types of defective sintered parts are produced due to mechanical and processing factors. The characteristic types of defects in sintering are as follows: 'crust', faulty sintering, burning, decarbonization, carbonization, cracks, and buckling.

Such types of defects as burning or faulty sintering occur very rarely. If processing instructions are strictly observed, it is also possible to completely eliminate other types of defects, such as 'crust' and cracks.

'**Crust**' is a disruption of the surface of a part or a lifted outer layer. The surface of the part just under the outer layer or 'crust' frequently retains the form of the external surface (chamfer, bevel, edge). Under the 'crust', as a rule, there are observed well visible carbon flakes. The degree of crust-formation on a part may differ, ranging from a small crevice on the face to the complete destruction of the part. Most frequently a 'crust' forms on the sharp edges and ribs of the part, i.e., in the least compacted portions of the part. Generally, 'crust' occurs in several parts in one boat, and mainly in those parts that are located in places adjoining the boat walls.

The 'crust' develops at a temperature of up to 600°C. The favourable conditions for its development are as fol. lows: lack of hydrogen, insufficient covering of parts with a filling, increased charging of parts into a boat, and high rate of heating of parts. The formation of the 'crust' is explained by the evolution of gaseous hydrocarbons as a result of sublimation or decomposition of the plasticizing agent with the separation of solid carbon. At a certain concentration of hydrocarbons, they decompose in the pores of the surfaces of a part, leaving the separated carbon (soot) in them. The soot interferes with the sintering of the surface layers, destroying the part to some extent. A 'crust' reject is considered to be final, and is not corrected. To obviate it, the parts are carefully packed, covering them with a sufficient layer of the filling material which, in this case, will prevent the direct contact of the parts being sintered with the hydrocarbons formed in the furnace space.

At present, cases of rejects on account of 'crust' occur very rarely. They are, as a rule, produced by nonobservance of the specified technological process.

Faulty sintering results from nonobservance of the specified sintering process with regard to the temperature and speed of travel of the boats in the furnace. Faulty sintering is conducive to lowering the physicomechanical properties as compared with the standard values, especially as regards the density and bending strength. On considerable violation of the heating schedule, the insufficiently sintered parts differ noticeably in colour and dimensions as a result of incomplete shrinkage.

This type of reject can be corrected. The insufficiently sintered parts are again placed into the furnace, where the sintering process is carried to its completion. However, additional sintering of parts cannot always be effected according to the usual sintering schedule, by simply charging the parts a second time into the furnace. The schedule for additional sintering depends on the extent of faulty sintering, and must be specified separately for each given case.

It should be noted here that though this type of reject can be corrected, the resintering of parts results in somewhat lowering their mechanical properties as compared with parts that have been sintered only once. That is why the sintering schedules should be carefully observed in order to obviate the development of this type of reject.

Burning results from the use of a too high sintering temperature as compared with the prescribed one. The external signs of burning are blisters, swellings, and blowholes on the surface of a part, and high internal porosity. The structure of the burnt alloy is very coarse, and its physicomechanical properties are extremely poor. Burning is a final type of reject which cannot be corrected.

Decarbonization results from a deviation in the composition of the gaseous medium in sintering, or from the decarbonizing effect of the filling material. In case of decarbonization, the sintered part suffers from a deficiency of carbon. A decarbonized part exhibits clear, bright spots. The fracture of the part may have a distinct core of a light colour that gradually passes over into darker, dull, peripheral layers.

A deficiency of carbon in the alloy results in deterioration of its physicomechanical properties and, mainly, in the embrittlement of the alloy.

Slightly decarbonized alloys can be corrected by sintering them in a carbonaceous filling and decreasing the stream of hydrogen to the minimum. In each given case, the correction schedule is selected individually, since the degree of decarbonization may be different.

When decarbonization is considerable and even causes a change in the form of a part, such parts cannot be corrected. In such a case, they should be considered as final rejects.

Carbonization of parts results from sintering alloys with a high carbon content and in a medium having an increased carbon content. Strong carbonization of the alloy can be observed on the fracture of a specimen in the form of separate dark spots. Examination of the structure of the part under a microscope clearly shows the amount of graphite and the nature of its distribution. Graphite is isolated more frequently near the edges of the piece, and is but rarely met with, dispersed throughout the entire fracture. Excessive carbonization of an alloy causes a decrease in its wear resistance.

To correct a reject caused by carbonization, the part must be resintered in a less carbonaceous medium, which can be created by increasing the amount of hydrogen passed through the furnace, as well as by using a low-carbon filling or a filling without any carbon.

Cracks, as a rule, occur mainly in parts of intricate shape, usually in those places where there is a transition from a denser to a less dense portion of the part. Cracks result from abrupt heating of a part to elevated temperatures, at which the part expands, and the internal stresses are rapidly relieved in its separate portions. This type of reject is considered to be final and cannot be corrected.

Buckling results either from a nonuniform density of the briquetted part and is caused by the various degrees of shrinkage, or from the part bending under the effect of its own mass or the weight of the overlying parts; and also because of the unevenness of the graphite plates on which the parts are arranged. Parts of a great length and small thickness are especially liable to buckling.

To prevent buckling in sintering, the parts should be properly packed. Slight buckling can be corrected either by resintering the parts under a load or by hot pressing.

Parts with considerable buckling are considered to be final rejects.

Consequently, from what has been stated above, it appears that most types of rejects are final and cannot be corrected; moreover, parts obtained from those types of rejects that are subjected to correction have poor mechanical properties. That is why during the sintering operation, the specified schedules should be carefully observed.

At present a method has been developed for reprocessing sintered rejects, using the procedures for producing sintered metal carbides. This method, however, does not enable reprocessing of all grades of sintered carbides, and is connected with great losses. Moreover, the carbide phase grains become very coarse as a result of the high-temperature treatment envisaged by this method.

This method is based on a high-temperature treatment of faulty sintered parts, which is conducive to the formation of waste with an increased brittleness. The waste is ground to the same granularity as that of the starting powders of coarse-grained carbides.

The high-temperature treatment results in partial evaporation of cobalt and the burning of carbon, owing to which the mixtures prepared according to the aforementioned method will not contain the required contents of the components.

If waste of different grades of alloys are collected together, this may also result in deviations from the required contents of the components in a mixture.

That is why when preparing a mixture it is necessary to add to the ground waste the deficient amount of a particular intermediate product in the form of tungsten carbide, cobalt or complex titanium-tungsten carbide. The amount added is calculated on the basis of the chemical composition of the ground waste.

After adding the intermediate products, the mixture is additionally ground. All the subsequent operations are effected in accordance with the technological process for production of sintered carbides.

LABOUR PROTECTION AND ACCIDENT PREVENTION

Enterprises engaged in producing sintered carbides are included in the class of metallurgical works at which the technological process involves the use of powdered materials, explosive and inflammable substances, and is accompanied by the evolution of gases, dust, vibrations, and noise.

When operating grinding and mixing equipment, the worker has to handle metal powders (cobalt, tungsten, tungsten carbide, titanium, tantalum, niobium, and others). The dust-laden air penetrates into the human organism through the respiratory system and gastro-intestinal tract, and causes irritation of the mucous membranes of the nose and throat, and disease of the lung tissue. Therefore, the content of dust is limited by permissible concentrations per cubic metre of air. The content of dust in the air within the range of permissible concentrations does not cause diseases. The permissible concentration for cobalt is 0.5 mg/m^3; for tungsten, 6 mg/m^3; and for molybdenum, 4 mg/m^3.

To obviate diseases that may be caused by metallic dust, especially great attention should be paid to the proper operation of the forced-exhaust ventilation, and to individual means of protection, such as working clothes, dust-proof goggles, and the like. Safeguards should be provided to prevent injuries from the moving parts of equipment.

When operating press equipment, work with moving parts of mechanisms is mainly involved. That is why in the briquetting operation, special care should be taken to keep the equipment in good order and to observe the safety rules in such operations as mounting the press tools, cleaning the punches and press, etc. The aforesaid operations are carried into effect only after the press has been stopped. During the operation of the press, it is necessary to check whether there are safeguards on the moving parts.

When preparing powders for briquetting, involving the use of petrol, it is necessary to watch the operation of the forced-exhaust ventilation, and to take measures for preventing the inflammation of petrol. Therefore, it is prohibited to use an open fire in a shop where mixtures are prepared with a plasticizing agent; neither is it permitted to

employ faulty electrical devices and mechanical equipment that might cause sparking.

When operating the furnace equipment, measures should be taken, first of all, to protect the personnel from electric shock, i.e., the electric wires should be kept in good order, and the electrical equipment should be properly grounded.

In the production of sintered metal carbides there are employed electric furnaces that operate in a hydrogen atmosphere. Hydrogen is a light gas which is both colourless and odourless. It is harmless in itself; but when combined with oxygen and air, it is capable of forming an explosive gas mixture which detonates with a great force. That is why the rules for working with hydrogen should be strictly observed, namely: hydrogen should be supplied into the furnace prior to heating it up; the furnace should be blown through with hydrogen so as to completely remove air from the furnace space. When operating furnaces equipped with an alundum muffle or tube and a molybdenum heating element, hydrogen should be passed not only into the furnace space, but also into its housing so as to completely remove air from it. After this has been carried out, the furnace may be switched on for heating it up. Hydrogen should be burned at the furnace inlet and outlet (for charging and discharging, respectively). Hydrogen may be ignited with the furnace started, only after the latter has been completely freed of air, which is controlled by igniting a hydrogen sample taken in a test tube. A characteristic, so-called 'barking' shows that the air has not been completely removed from the furnace chamber. In order to prevent accumulation of hydrogen and the occurrence of an explosion, the operation of the forced-exhaust ventilation must be closely watched.

In sintering furnaces, the hydrogen used is additionally dried by passing it through a tube containing phosphoric anhydride. The operations of filling and washing the tubes should be conducted with the utmost care, for they are dangerous and may cause burning of the hands and face of the worker.

When operating the furnaces, it is prohibited to open simultaneously both the doors of the furnace (for charging and discharging), and to stand opposite the charging or discharging opening.

When operating furnaces equipped with graphite tubes, that are employed for reducing tungsten anhydride with carbon, and also for producing carbides, the safety rules are the same as those for operating furnaces equipped with a molybdenum heater. In this case, additional measures must be taken to prevent poisoning by carbon monoxide that is evolved when the above-mentioned processes are effected.

Carbon monoxide penetrates into the blood and reacts with hemoglobin, thus preventing access of oxygen to the cells. As a result, oxygen deficiency occurs, which is accompanied by giddiness, nausea, and in heavy intoxications, by fainting. The permissible concentration of carbon monoxide in air is 0.02 mg/m^3.

To prevent intoxication by carbon monoxide, the processes must be conducted until the carbonaceous products have been fully combusted, and efficient operation of the ventilation equipment must be assured.

The workers who service the furnaces should wear protective goggles and gauntlets.

In general, the problems and tasks of safety engineering include a thorough study of the nature of each operation to be effected and work to be done. Of no small importance are the organization of the working place, its proper illumination; the temperature, humidity, air currents in the industrial atmosphere; and also such things as the colour of the walls, floor, equipment, the convenient arrangement of the latter, etc.

CHAPTER VIII

Checking of Quality in Manufacturing Sintered Metal Carbides

In the process of manufacturing hard or metal-powder alloys, it is necessary to inspect the quality of the main and auxiliary materials, semi-finished products, and finished products, as well as to check whether the manufacturing process is carried out correctly.

Constant checking of all the manufacturing operations is required because the manufacture of sintered metal carbides is a complex process involving many operations.

Tables 8.1, 8.2, and 8.3 present the methods of inspecting the main and auxiliary materials and semi-finished products and of checking the manufacturing processes.

Great attention should be paid to the testing of finished products.

The methods used for inspecting various materials are commonly known techniques. The methods of testing finished products, that are specific to the production of metal-powder alloys, are described below.

8.1. Metallographic Examination of the Quality of Sintered Carbides

INSPECTION OF MICROSTRUCTURE OF SINTERED CARBIDES

All the manufactured batches of metal-powder products are subjected to metallographic examination. For this purpose, not less than 10 specimens are taken from each batch of products. Faulty quality of the alloys, due to excessive carbonization or decarbonization, as well as non-uniform distribution of phases can be detected only by metallographic examinations.

Table 8.1

Inspection of Main and Auxiliary Materials

Raw material	Sampling	Testing
Tungsten anhydride	From each batch of tungsten anhydride	Chemical analysis for content of impurities. Determination of dispersity
Tungsten anhydride from paratungstate		
Titanium dioxide		Chemical analysis for content of impurities
Cobalt oxide (mixture of cobaltons and cobaltic oxide)		Chemical and spectral analysis for content of impurities. Determination of bulk mass
Metallic tantalum	Accepted according to the Manufacturer's certificate	chemical composition given in the
Soot	From each batch	Determination of moisture content, ash content, sulphur content, volatile matter, and over-size product
Ethyl alcohol (hydrolysis)	From each container	Determination of alcohol concentration
Alcohol, rectified (or sulphidic)	—	—
Aviation petrol	From each container	Chemical analysis of lead
Synthetic rubber		Determination of ash content
Solution of synthetic rubber in petrol		Chemical analysis for rubber content; determination of ash content in the solution
Corrax	Accepted according to the Manufacturer's certificate	
Electrolytic hydrogen	Samples are taken directly from the furnace	Chemical analysis for oxygen and determination of moisture content
Paraffin	Accepted according to the Manufacturer's certificate	
Phosphoric anhydride		
Graphite grit	—	The presence of dust in the grit, passing through 0.34-mm mesh, is not allowed

Inspection of Semi-Finished Products

Semi-finished product	Sampling	Testing	Notes
Powdered tungsten Brown tungsten Charge for preparing tungsten carbide	From each batch	Chemical analysis: determination of dispersity Determination of dispersity Chemical analysis for determining C_{tot}	For uncrushed tungsten, the bulk mass is determined three times each shift
Tungsten carbide	From each individual and enlarged batch	Chemical analysis for determining C_{tot} and C_{free}; determination of dispersity	Fe is determined in the enlarged batch
Charge for preparing double (triple) titanium-tantalum-tungsten carbide		Chemical analysis for determining C_{tot}	Fe is determined in the enlarged batch
Double (triple) titanium-(tantalum)-tungsten carbide	From each batch charge	Chemical analysis for determining C_{tot} and C_{free}; determination of dispersity	Ta and Ti are determined in the triple titanium-tantalum-tungsten carbide
Tantalum carbide Powdered cobalt Mixture for WC-Co alloys	From each batch	Chemical analysis for determination of C_{tot} and C_{free} Chemical analysis for determining the oxygen content, and bulk mass Chemical analysis for determining C_{tot}, C_{free}, Fe, Co Process testing of the mixture according to specifications	
Mixture for TiC-WC-Co and TiC-TaC-WC-Co alloys		Chemical analysis for determining C_{tot}, C_{free}; Co; Ti; Fe; O_2. Process testing of mixture	Ta is determined in titanium-tantalum-tungsten mixtures

Table 8.3

Checking of Manufacturing Processes

Operation	What is checked	Checking done	
		by whom	how and how often
Roasting (drying) of soot	Roasting temperature Mass of the material charged	Foreman	1 or 2 times each shift, with the aid of instruments Control weighing 1 or 2 times during a shift
Preparation of brown tungsten oxide	Powder dispersity Furnace temperature in zones Quantity of hydrogen Mass of the material to be charged Speed of travel of boats	Worker, foreman	Determination of adsorption every 4 hours 2 times during a shift, with the aid of instruments Control weighing 1 or 2 times during a shift According to the time the boats emerge from the cooler
Preparation of powdered tungsten	Ditto	Ditto	Determination of adsorption once during a shift
Preparation of powdered cobalt	Ditto Determination of the bulk mass	Ditto	Ditto Determination of the bulk mass once during a shift

Continued

Operation	What is checked	Checking done	
		by whom	how and how often
Preparation of the charge for obtaining tungsten carbide	Charging of ingredients Mass of balls Mixing time	Foreman	Weighing is effected by the worker in the presence of the foreman Once a month, by sifting out on a screen and weighing According to log records and tachometer
Carbonization of tungsten	Furnace temperature Quantity of hydrogen Mass of boat charge	Worker, foreman	Every hour, with instruments Once each hour, with aid of rotameter Selectively, 2 times during a shift
Preparation of the charge for manufacturing double (triple) carbide	Charging of ingredients Mass of balls Mixing time	Foreman	Weighing is effected by the worker in the presence of the foreman Once a month, by sifting out on a screen and weighing According to log records and tachometer
Carbonization of double (triple) carbide	Furnace temperature	Worker, foreman	1 or 2 times during a shift, with the aid of an instrument

Continued

Operation	What is checked	Checking done	
		by whom	how and how often
Carbonization of double (triple) carbide	Quantity of hydrogen Mass of boat charge	Worker, foreman	1 or 2 times during a shift, by means of rotameter Selectively, weighing a boat 1 or 2 times during a shift
Grinding of tungsten, tungsten carbide, and double carbide	Mass of the grinding bodies Size of the grinding bodies Grinding time	Foreman	Weighing once a month Sifting through a screen once a month According to log records and tachometer
Screening of tungsten, carbides, cobalt	Correct choice of gauze Control screening	Foreman, laboratory	—
Grinding of mixtures	Charging the components of a mixture Grinding time Mass and grinding balls Rotational speed Filtration of liquid mixture through a screen	Foreman	Weighing is effected by the worker in the presence of the foreman According to log and drum tachometer Once a month by weighing and screening Once during a shift, by means of tachometer or timer

Operation	What is checked	Checking done	
		by whom	how and how often
Drying of mixtures after grinding	Drying temperature	Foreman	Twice during a shift, with the aid of an instrument
Screening of mixtures	Correct choice of gauze Control sifting	Foreman, laboratory	When putting on a new gauze Once during a shift
Mixing the mixtures with a plasticizing agent	Amount of synthetic rubber solution Drying temperature Compressibility of mixture Uniformity of intermixing	Worker, foreman	—
Granulation of mixtures	Granulation time Mass of the charged mixture Compressibility of granules	Ditto	Selectively, weighing 1 or 2 times during a shift Selectively, compacting the granules of two batches during a shift
Briquetting	Briquetting pressure Mass of briquetted part Outer appearance, size, and mass of parts Inspection of dies	Worker, fitter, foreman	By means of pressure gauge Selectively, by weighing According to the size and mass of 10 per cent of the parts. According to the outer appearance of 100 per cent of parts According to the size and surface finish; checking to drawings

Continued

Operation	What is checked	Checking done	
		by whom	how and how often
Presintering	Shrinkage of sintered parts		Determination of dimensions of sintered specimens. 2 pieces from each tray; the dimensions and macrostructure are checked
Machining	Wheel grade Wheel rotational speed	Foreman, worker	Checking proper machining by comparing with drawings
Sintering	Temperature in zones Quantity of hydrogen Speed of travel Charging mass Residual pressure Determination of coercive force of test specimens for each grade of alloy	Laboratory, Inspection Department	1st and 2nd zones, once a day; 3rd zone, every 15 minutes By means of rotameter Checking gears on pushers Selectively, weighing twice during a shift By means of vacuum meter

The following characteristics of sintered carbides are checked by means of metallographic examination:

(a) degree of porosity;
(b) inclusion of free carbon (graphite);
(c) nature of distribution of Co-phase;
(d) the presence and nature of η-phase inclusion;
(e) grain size of WC-phase;
(f) grain size of TiCWC-phase.

EXAMINATION OF DEGREE OF POROSITY

To determine the degree of porosity, a non-etched microsection is examined under a microscope having a magnifying power of $100\times$. Pores are visible as areas of a round or irregular form.

Depending on the pore size, they are subdivided into two groups:

(a) up to 50 μ;
(b) over 50 μ.

Porosity of the first group is determined by comparing the microsection under examination with the porosity scale. To evaluate porosity of the second group, the total length of all the pores throughout the entire surface of a microsection is calculated. The size of a pore is measured along its longest dimensions.

DETERMINATION OF FREE CARBON (GRAPHITE) INCLUSIONS

In order to detect the free carbon (C-phase) inclusions that are observed on a non-etched microsection as pocket-shaped conglomerates or separate small areas, the entire surface of the microsection is examined under a microscope having a magnifying power of $100\times$.

The content of free carbon inclusions is characterized by the total area of graphite inclusions, expressed as per cent of the selected field of view.

To evaluate the graphite content, the selected field of view with the maximum content of free carbon inclusions is compared with microphotographs of the graphite-inclusions scale.

DETERMINATION OF NATURE OF Co-PHASE DISTRIBUTION

The nature of Co-phase distribution is observed by examining a non-etched microsection under a microscope having a magnifying power within the range of 1350 to 1500×. Ten fields of view in various parts of the microsection are examined, and in the metallographic examination certificate there are noted data characteristic of the Co-phase distribution, which may be uniform or non-uniform. In the case of uniform distribution of Co-phase, the thickness of cobalt interlayers is determined with the aid of a scaled eyepiece. In the case of non-uniform distribution of Co-phase, there is additionally calculated the quantity of Co-phase conglomerates in 10 fields of view, and the maximum conglomerate size is indicated.

DETERMINATION OF PRESENCE AND NATURE OF η-PHASE INCLUSIONS IN MICROSTRUCTURE OF ALLOYS OF TUNGSTEN GROUP

The presence of η-phase is detected through examination of a microsection etched according to schedule 1 (see Table 8.4). The etched microsection is examined under a microscope having a magnifying power within the range of 1350 to 1500×. The absence or presence of η-phase is noted in the metallographic examination certificate; also noted there are the nature of its distribution and the form of inclusions (for example, on the periphery, in the center, or on the entire surface of the microsection; in the form of so-called 'ponds', 'lace', or small inclusions).

Depending on the degree of etching, the colour of η-phase inclusions as viewed under the microscope, varies from reddish-orange to brown.

DETERMINATION OF GRAIN SIZE OF WC-PHASE OF ALLOYS OF TUNGSTEN GROUP

The alloys of this group contain the following main phases: WC-phase (tungsten carbide), Co-phase (solid solution of tungsten carbide in cobalt). There may additionally be present η-phase (double carbide of tungsten and cobalt, Co_3W_2C),C-phase (free carbon or graphite).

The grain size of WC-phase is determined by examining an etched microsection, the etching operation being effected according to schedule 2 (see Table 8.4), and after washing the microsection, according to schedule 3. The microstructure of the alloy is determined by examining two specimens, one having the maximum and the other the minimum values of coercive force.

After etching, the microsection is examined under a microscope: 100 grains, for fine-grained alloys, and 200 grains, for coarse-grained alloys, are measured by the point method in various portions of the microsection, the magnifying power being within the range of 1350 to 1500×. For this purpose, a lattice scale (1:100) is inserted into the eyepiece; the grains between intersections of the cross-lines of the eyepiece scale are measured, and the percentage of grains is calculated according to granularity classes. The grain size is determined by its maximum dimensions.

When there are areas of conglomerates of large grains of WC-phase, the number of such areas are calculated in 10 fields of view.

DETERMINATION OF GRAIN SIZE TiCWC-PHASE IN ALLOYS OF TITANIUM-TUNGSTEN GROUP

Alloys of the titanium-tungsten group comprise the following main phases: TiCWC-phase (solid solution of tungsten carbide in titanium carbide), WC-phase (tungsten carbide), Co-phase (solid solution of tungsten carbide and titanium carbide in cobalt). The presence of C-phase (graphite) is also possible.

The grain size of TiCWC-phase is determined with the aid of an etched microsection, in which half of the microsection is area etched according to schedule 3. After etching, the procedure used for determining the grain size of WC-phase is employed to determine the grain size of TiCWC-phase in various portions of the microsection, the percentage of grains according to granularity classes is calculated, and the data obtained is entered into the metallographic examination certificate. 'Ring-shaped structure' of the grains of TiCWC-phase, if present, is noted in the certificate.

Table 8.4

Etching Schedules

Etching schedule No.	Composition of etching agents and method of etching	Etching conditions	Purpose of etching	Etching effect	Notes
1	Freshly prepared mixture of equal volumes of 20% aqueous solutions of potassium ferricyanide and potassium hydroxide or sodium hydroxide	Temperature of 18 to 20° C; duration, 2 to 3 s	To detect η-phase in alloys of the tungsten group	η-phase assumes a reddish-orange colour and is bordered at the boundaries; WC- and Co-phases remain light in colour	Oxide film is easily rubbed off; therefore, the etched microsection should be dried on filter paper
2	Saturated solution of ferric chloride in concentrated hydrochloric acid	Temperature of 18 to 20° C; duration, about 5 min	To detect WC-phase in alloys of the tungsten group	Co-phase is coloured black; etching does not affect the other phases. On the dark background of Co-phase there are observable light-coloured grains of WC-phase	—

3	Freshly prepared mixture of equal volumes of 20% aqueous solutions of potassium ferricyanide and potassium hydroxide or sodium hydroxide	Temperature of 18 to 20°C; duration 5 min	To detect WC-phase in alloys of the tungsten group; TiCWC-phase, in alloys of titanium-tungsten group	WC-phase is distinctly bordered at the grain boundaries, while retaining a natural bluish colour; η-phase is etched out; Co-phase remains light. TiCWC-phase is bordered at the grain boundaries and coloured dark-yellow	Applied after etching according to schedule 2
4	Oxidation in air, with heating	Heating in a muffle furnace at 400°C during 45 min	To detect all phases in alloys of the titanium-tungsten group. To determine the grain size of Co-phase in the same alloys	TiCWC-phase is coloured dark-orange; WC-phase remains light. Co-phase is bordered at the grain boundaries, taking on a greenish or dark-red colour	

To determine the grain size of WC-phase in alloys of the titanium-tungsten group, use is made of the microsection which has been used for determining the grain size of TiCWC-phase. The microsection is treated according to schedule 4. The percentage of grains of WC-phase is calculated according to the granularity classes on the half of the microsection, which has been subjected to etching according to schedule 4.

PREPARATION OF MICROSECTIONS

Microsections are prepared on a fracture of a specimen in its smallest cross-section with an area not greater than 2.5 cm^2. To obtain an even smooth surface, it is polished with wheels made of green silicon carbide.

After polishing, the microsection should not have any cracks. The microsections are further treated on iron discs with boron carbide having a granularity of 80 to 90μ, and with diamond powder. When polishing, the boron carbide is wetted with kerosene or water. After polishing with boron carbide, the specimen is thoroughly rinsed with water or petrol, and wiped dry. The next polishing operation is effected with the use of diamond powder having a grain size of 3 to 15μ. The diamond powder in the form of a suspension in ethyl alcohol is put on the disc with the aid of a small glass rod and is thoroughly rubbed on it, the disc being wetted with ethyl alcohol during the operation. Each polishing operation is carried on until traces of the preceding operation have been eliminated from the microsection surface.

After the polishing operation, the microsection is washed with water or petrol and wiped dry. After the microsections have been fitted on wooden (beech) discs, they are subjected to finishing polishing with the aid of a diamond powder having a grain size within the range of 1 to 2μ, applied as an aqueous suspension prepared with the addition of transformer oil. The polishing operation may also be effected with the aid of a suspension prepared by mixing aluminium oxide and an alkaline solution of potassium ferricyanide; to prepare 1000 ml of the suspension, 5 to 10 ml of the etching agent used in schedule 1 are mixed with 40 ml of an aqueous suspension of aluminium oxide having a grain size up to 1μ (500 g of aluminium oxide in 1000 ml of water).

The quality of the polished microsection is checked under a microscope having a magnifying power of 100×. The microsection surface should be mirror-like, without any grooves and scratches; all pores and graphite inclusions should be distinctly visible.

Various types of equipment are employed for treating microsections. The surface of the specimens is levelled off with the aid of wheels made of green silicon carbide, that are mounted on grinding machines of various designs.

Subsequent polishing and grinding operations are effected on special surface grinding machines, where the specimens are mounted with the aid of molten sulphur or easily fusible alloys in such a way that only the surface of the hard-alloy specimen is exposed to the action of the abrasive. When grinding and polishing with the aid of diamond powder, the latter in the form of a suspension in ethyl alcohol is applied to horizontal discs made of grey iron. The suspension, continuously intermixed with air, is supplied dropwise on a rotating disc covered with coarse-fibered cloth or felt.

The microsections may also be treated without using a diamond powder. To this effect, there are employed machines for anode-mechanical grinding. In this case, the metal cathode of the machine is replaced by an electrically conducting wheel made of synthetic corundum, graphite, and bakelite; the anode is the microsection to be treated, and the electrolyte used is 1 per cent aqueous solution of borax. By gradually varying the treatment schedule (consisting in varying the current), there is obtained a mirror-like surface of the microsection, free of scratches and grooves.

EXAMINATION OF MACROSTRUCTURE

A rapid preliminary evaluation of the quality of the sintering operation is effected by examination of the macrostructure. This method, however, only allows gross deviations from the normal sintering process to be detected, and, thus, cannot replace metallographic examinations.

To examine the macrostructure, sintered specimens with external defects (such as, broken edges, cracks, etc.) are fractured by hammer blows. The fracture of specimens is then examined with a binocular or simple magnifying glass,

or under a microscope having a magnifying power of 20 to 40×.

The distinctive features of the macrostructure are as follows. Alloys with a normal structure present an even fracture of a grey colour, without any inclusions.

In the case of strong decarbonization of a medium-grained alloy, on the fracture, against a background of the uniform grey alloy, are seen separate bright points (or 'spangles') that are crystals of η-phase. In the case of fine-grained alloys, it is more difficult to detect decarbonization, on account of the great dispersity of η-phase. For these alloys, it is necessary to examine their microstructure.

In the case of excessive carbonization of an alloy during sintering, the fracture shows a characteristic pattern: the fracture presents minute spots in the form of 'pockets' of various size, depending on the degree of carbonization. The spots sometimes exhibit radial off-shoots; in other cases, small spots are distinguishable as dark points. In the case of large spots, the surface is rougher as compared with areas of normally sintered alloys.

Graphite inclusions become visible on the fracture only in the case of very strong carbonization.

Requirements to be met by the microstructure of metal-powder alloys are set forth in Table 8.5.

Table 8.5

Requirements to be Met by the Microstructure of Sintered Carbides*

Sintered carbide	Coercive force, oersted	Size of the main mass of WC grains, μ	Sintered carbide	Coercive force, oersted	Size of the main mass of WC grains, μ
BK2	—	—	BK11B	—	2-5
BK3	—	—	BK8	125-145	1-2
BK3M	230-280	0.5-1.0	BK8B	50-70	2-5
BK4	125-160	—	BK10	—	—
BK4B	—	2-5	BK15	—	1-2
BK6M	200-250	0.5-1.0	BK20	75-105	0.5-3.0
BK6	130-150	1-2	BK25	—	—

* Porosity should not exceed 0.2 per cent; graphite content, 0.2 per cent; the content of η-phase is inadmissible.

8.2. Determination of Density

The density of metal-powder alloys is determined for checking the sintering operation. The density of the alloy shows whether the specified schedule of sintering has been observed.

In the case of normal sintering, the density of specimens of metal-powder alloys of different grades should lie within a certain range. If the sintering schedule is not observed, sintering will be faulty and the hard alloys will have a lower density, because the parts thus produced have a high porosity. The undersintered parts can be corrected by resintering. The density of a metal-powder specimen is determined hydrostatically, by weighing the specimen in air and in distilled water. The density is calculated from the formula

$$\rho = \frac{M_1}{M_1 - M_2}, \text{ g/cm}^3$$

where M_1 = mass of specimen in air, g
M_2 = mass of specimen in water, g

Metal-powder parts having a mass up to 200 g, are weighed on an analytical balance; while those having a mass over 200 g (up to 1 kg), on a technical balance. The specimens should be free of cracks, and their surface should be cleaned from contamination, grease, etc.

The left-hand balance pan should be equipped with a device for weighing in air and in distilled water. For weighing in water, it is common practice to place specimens in a basket of thin stainless steel wire of a diameter not more than 0.5 mm, or of sheet iron not more than 0.5 mm thick.

The zero point of the balance must be checked prior to each weighing. Checking is carried out with the basket immersed in water.

When the mass of a part is more than 40 g, its density is determined but once, whereas in the case of small parts of a mass less than 40 g, several parts are weighed together, provided that their total mass does not exceed 200 g.

The density is determined by the following procedure: a specimen is put into the left-hand balance pan and weighed in air. The weighing data are recorded to the nearest 0.001 g

(on an analytical balance), or to the nearest 0.01 g (on a technical balance). Then a glass with distilled water is placed on the pan, a wire is suspended (during the weighing on the balance the wire is immersed in the glass), the balance zero point is checked, whereupon a specimen is secured in the wire loop and immersed in the water. It is necessary to see that there are no air bubbles on the specimens immersed in the water, for they can lead to erroneous weighing results.

If there are bubbles present, the specimen should be extracted from the water and again immersed into it. The specimens are weighed in water with the same accuracy as in air.

After the weighing results have been entered into the log, the density is calculated from the formula to the nearest 0.05 g/cm^3.

8.3. Determination of Coercive Force

Hard alloys possess magnetic properties, which is explained by the presence of a ferromagnetic constituent, cobalt.

Coercive force is called the magnetizing force (magnetic-field strength) that is necessary to annual the residual magnetism of a ferromagnetic body that has previously been magnetized up to the saturation limit.

The installation for determining the coercive force comprises a direct-current electromagnet for magnetizing the specimen, and a coercive force meter for creating a magnetic field.

The coercive force meter is provided with a base accommodating coils and a vertical pipe. Passing through the pipe is a thin wire, from the end of which there is suspended a device for securing the specimen. The wire material is non-magnetic. At the bottom of the pipe there is a device for damping the wire oscillations ('pendulum'), which is essentially an impeller immersed in oil. The wire position is controlled by means of an optical system (system of lenses and a lamp). The lenses serve to focus the shadow of the 'pendulum' on a frosted glass with two vertical lines inscribed on it.

The coercive force is determined in the following manner. A metal-powder specimen is put into the magnetic field of a direct-current electromagnet, where it is magnetized (the current is equal to 6 to 8 amperes; the duration of magnetization, fractions of a second). After magnetization, the specimen is transferred to the suspended holder in the coercive force meter, when there is no current flowing through its coil. The metal-powder specimen should be arranged in such a manner that its field will be directed against the field created by the coil of the coercive force meter.

Screws are employed for setting the pendulum into the zero position; this is determined by the coincidence of the pendulum reflection on the frosted glass and the vertical lines on it. Then current is gradually supplied to the meter coil through an autotransformer or rheostat, after which the magnetic field of the coil begins to steadily increase, this field interacts with the field of the specimen, which is repelled, causing the pendulum to deflect. As the magnetic field of the coercive force meter coil increases, the deflection of the pendulum increases, too; but as the magnetic field of the coil gradually demagnetizes the specimen, the pendulum deflects less and less and finally occupies the zero position after the specimen has been fully demagnetized.

The coercive force H_c, expressed in oersteds, is determined from the formula

$$H_c = AK$$

where A = the current in the coil of the coercive force meter, at which full demagnetization of the specimen is achieved, amp

K = constant of the coil, determined for each coercive force meter (it is indicated in the instrument certificate), otherwise called the instrument constant

To determine the value of K, it is necessary to have standard plates, the coercive force of which is known.

Previously magnetized standard plates are suspended from the pendulum of the coercive force meter to be tested, after which they are demagnetized; the current required for their demagnetizing is measured. The current is deter-

mined for three standard plates having various values of H_c. The value of K is obtained as the arithmetic mean of the three results obtained.

The coercive force is also measured on semi-automatic instruments (control-and-measuring computer apparatus).

The semi-automatic coercive force meter operates according to the principle based on measuring the gradient of a magnetic field which is created by a magnetized specimen placed into the zone of a magnetic-modulation pick-up.

In this instrument, magnetization occurs in an open magnetic circuit. The magnetizing field is non-uniform, impulsive, whereas the demagnetizing field is uniform.

On placing the part into the measuring position, the magnetizing circuit is energized, and the specimen is magnetized with a pulse current in the field of a magnetizing solenoid. Then the time relay switches in the current in the demagnetizing solenoid, and the part is demagnetized.

When the demagnetizing force becomes equal to the coercive force, and the gradient in the pick-up field has a minimum value, the magnetic-modulation pick-up emits a signal for switching off the demagnetizing current. At this very moment, the oersted meter indicates the coercive force of the part under investigation.

The coercive force meter can be used to carry out measurements within the range of 3 to 300 oersteds, with the measuring error averaging ± 1.5 per cent. The accuracy of the instrument reading is checked by means of standard specimens with coercive forces of approximately 50, 150 and 250 oersteds. This instrument may be used for measuring the coercive force of hard-alloy parts of any shape, containing the magnetic constituent (cobalt phase) in an amount of 3 per cent and higher, having a size up to $20 \times \times 20 \times 50$ mm and mass within the range of 5 to 200 grams. When the mass of a part is less than 5 grams, it is permitted to measure a bundle of small-size parts, the total mass of which amounts to 10 to 15 grams.

When testing, the following sequence of operations should be observed.

Prior to starting the test, the magnetic unit is placed at a distance of not less than 200 mm from the electronic unit, which is grounded (the instrument is supplied with alterna-

ting current from a voltage stabilizer or autotransformer having an output voltage of 220 ± 5V).

Then the instrument is switched-in and heated up for a period of not less than 10 minutes. Before starting work and immediately after work, the condition of the instrument is checked with the aid of three standard specimens having coercive forces of approximately 50, 150, and 250 oersteds. Deviations from the true values of the standard specimens should not exceed ±1 oersted for a standard having the minimum coercive force, and ±3 oersteds for a standard having the maximum coercive force. After having properly prepared the instrument, the coercive force is measured. For this purpose the specimen is placed into a measuring container with its broad base in the horizontal plane and its long axis along the container axis; the container is then pushed into the magnetic unit up to the limit, i.e., until the terminal switch is actuated and the container is retained in this position until the oersted meter has been read off. When the pointer stops, it is necessary to read off the oersted meter. The next measurement is made after the 'cycle' lamp is lighted.

The measuring instrument scale is graduated in oersteds, and the oersted meter is read off to the nearest 1 oersted.

The coercive force indirectly characterizes the granularity of the alloy, since its value depends on the grain size of WC-phase. This is explained by the fact that, provided the cobalt content is the same, the size of the areas of the cobalt phase depends on the grain size of the carbide phase. The finer the grain of WC-phase, the thinner the cobalt interlayers and the higher the coercive force of the alloy, and vice versa.

The coercive force also depends on the cobalt content. The higher the cobalt content, the thicker the cobalt interlayers and the lower the coercive force. That is why relative evaluation of the granularity of an alloy by means of measuring the coercive force, is practicable only for alloys having a fixed cobalt content.

The coercive force of normally sintered parts should lie within the range specified in Table 8.5.

If the coercive force is greater, this shows that sintering has been carried out at a temperature that was too low.

In such a case, the parts can be corrected by additional sintering conducted according to a specially selected schedule.

The coercive force of an alloy decreases as the sintering temperature rises. Parts with a low coercive force cannot be corrected; they will exhibit coarser grains of WC-phase and possess reduced wear resistance when used.

If the parts are undersintered to an appreciable extent due to a very low sintering temperature, the coercive force also decreases. In this particular case, a decrease in the density of the alloy because of the great number of pores contained therein, may serve as an indication of deviation from the sintering schedule.

Determinations of the density and coercive force can be used to ascertain whether the proper sintering temperature schedule has been adopted.

8.4. Determination of Hardness

Hardness signifies, in general, the resistance of a solid body to penetration of another body into it. Hardness is one of the main properties of a metal-powder alloy, as the wear resistance largely depends on its value. The hardness of a metal-powder alloy is mainly affected by the content of carbide phase and the grain size of this phase. Hardness tends to increase as the content of the carbide phase increases or its grain size becomes finer. Titanium-tungsten alloys are characterized by a higher hardness than tungsten alloys, because titanium carbide is harder than tungsten carbide. Hardness also tends to increase with density.

The hardness of a metal-powder specimen is tested on the Rockwell machine, using scale *A*.

The principle of determining the hardness of a metal powder alloy on this machine consists in the following. A metal-powder part is indented by a diamond cone under two successively applied loads: a preliminary load of 10 kgf and then a total load of 60 kgf. The hardness of the alloy is measured by the difference in the depths of penetration of the diamond cone under the two loads. The hardness number depends on the depth of penetration of the diamond

cone, and is determined from the formula

$$HRA = \frac{B_1 (n_1 - n)}{c}$$

where B_1 = constant value, for cone $R_1 = 0.2$
n_1 = depth of penetration of diamond cone under 60-kgf load on relieving it and leaving the 10-kgf load
n = depth of penetration of diamond cone under a preliminary load of 10 kgf
c = depth of penetration of cone by 0.002 mm (the value of one division of the indicator dial)

Prior to testing on the machine, it should be checked; to this effect, the instrument readings are verified.

The instrument reading should correspond to the hardness of steel standard plates that are furnished together with the machine. Moreover, the correctness of the instrument readings is checked once a week with the aid of a standard hard-alloy plate. This is necessitated by the fact that the depth of penetration of the diamond cone into the hard alloy specimen is small, mainly, it is only the cone apex, having a rounding radius of 0.2 mm, that penetrates into the alloy. Cones with such rounding radii, that have been adopted as suitable, may differ in shape and produce different results; however, this is not detected when determining the hardness on steel standard plates, because the diamond cone is capable of penetrating relatively deeply into steel. Therefore, to obtain comparable results the hardness of metal-powder alloys must be determined by comparing it with the hardness of standard hard-alloy plates with the following *HRA*:

T30K4	92
T15K6	90
BK8	88
BK15	86
BK25	83.5

The standard hard-alloy plates should be thoroughly ground and polished with a diamond wheel or diamond powder.

When using the standard (or reference) plates, the hardness value is calculated from the formula

$$HRA = H_a - \frac{H_a - H_b}{H_N - H_K}(H_N - H_M)$$

where H_a = hardness of the reference plate with a maximum hardness

H_b = hardness of the reference plate with a minimum hardness

H_N hardness (average value) of the reference plate with a maximum hardness, when the hardness has been determined with a given cone

H_K = hardness (average value) of the reference plate with a minimum hardness, when the hardness has been determined with the use of a given cone

H_M = hardness (average value) of the specimen being tested, when the hardness has been determined with the use of a given cone

The value of H_N, H_K, H_M are determined as the arithmetic mean of the hardness numbers read off from the instrument scale.

The surfaces of the specimens (both the side to be tested and the back side) should be strictly parallel and fit tightly and firmly to the supporting table of the machine; any deviation from the parallelism should not exceed 0.05 mm over a length of 20 mm. To render the specimen sides parallel, it is ground with a wheel made of green silicon carbide on a ceramic binder, or with diamond wheels on a metal or organic binder. The thickness of the layer removed by grinding should be not less than 0.2 mm. In order to obviate the formation of convexity on the specimen under the effect of the load applied, the minimum thickness of the specimen being tested should be not less than 1 mm.

Hardness is determined on the Rockwell machine as follows. The specimen to be tested is put on the supporting table which is raised by turning the knob of the lifting screw until the specimen contacts the diamond cone.

Then a preload of 10 kg is applied to the specimen to this effect, the knob is turned until the small pointer of the

instrument indicator coincides with the black point on the scale, and the big pointer is in the vertical position. The big pointer should not deviate from the vertical position by more than ± 5 divisions. In case the small pointer passes beyond the black point, it is necessary to select another point on the surface of the specimen, and begin testing again. After the big pointer coincides with the vertical position, the indicator rim is turned until the black scale zero division coincides with the big pointer.

After the preload has been applied to the specimen, the total load is also applied to it; to this effect, the main load lever is released by lightly pressing on the clamp, whereby the load is gradually transmitted to the lever. The total load is relieved by gradually resetting the starting handle into its initial position, whereby the preload is still applied. On relieving the total load, the indicator reading is recorded according to the external black scale; then the table is lowered by turning the knob of the lifting screw in the opposite direction.

To obtain reliable data, the distance from the centre of the indentation to the outer edge of the specimen or to the centre of another indentation should be not less than 2.5 mm; when measuring the hardness of small specimens, the permissible distance from the specimen edge is not less than 1 mm.

Hardness is determined by testing three specimens and calculating the arithmetic mean of the test results.

Determination of hardness is mainly used to detect occasional mistakes in marking of alloy grades or to reveal undersintered parts.

8.5. Determination of Bending Strength

The strength of a solid body is its ability to resist the action of external forces. The mechanical strength of a body is usually characterized by the magnitude of the breaking loads applied in compressive, tensile, bending, twisting tests, etc. Ultimate strength is the highest load applied to a specimen prior to breaking, divided by the original cross-sectional area of the specimen. The mechanical strength of a hard alloy is one of its principal properties, and taking

into account that in most cases metal-powder products are subjected to the effect of bending loads, the ultimate bending strength is their main characteristic. The ultimate bending strength is inversely proportional to hardness, and tends to increase with the percentage of the bonding metal (cobalt). Consequently, the bending strength of hard alloys is mainly affected by their chemical composition, as well as by the grain size of the carbides and the thickness of layers of the bonding metal (cobalt). In comparison with tungsten alloys, titanium-tungsten alloys possess less strength, as titanium carbide is more brittle than tungsten carbide.

Of great importance for the ultimate bending strength is the size of the interlayers of the bonding (cobalt) phase; for the thicker the interlayer, the lower the local stresses and the higher the bending strength. The bending strength of an alloy tends to decrease as the interlayers of the bonding phase decrease. The thickness of the interlayers, in its turn, depends on the chemical composition of the alloy and the grain size of the carbide phase. The thickness of the interlayers tends to increase with the content of the bonding phase in the alloy, and with the grain size of the carbide constituent.

The ultimate strength of transverse bending of hard-alloy specimens is determined by applying a concentrated force to a specimen lying freely on two supports. In this method of testing, a metal-powder specimen lying freely on two supports is broken by a statical load applied to its centre.

The ultimate bending strength of a specimen under the action of a concentrated load is calculated from the following formula:

$$\sigma = \frac{M}{W} = \frac{3Pl}{2bh^2}, \quad \text{kgf/mm}^2$$

where $M = \frac{Pl}{4}$ = maximum bending moment, kgf·mm

$W = \frac{bh^2}{6}$ = moment of resistance of a specimen of rectangular cross section, mm^3

P = breaking load, kgf

b = specimen width, mm

h = specimen height, mm

l = distance between the supports, mm

Universal testing machines of capacities of 4 to 5 tons are employed for bending tests. These machines are equipped with a special device for setting the specimens in place. The device is provided with exchangeable hard-alloy supports 5 to 6 mm in diameter, with surfaces ground to the 6 to 7th class of surface finish; the distance between the supports should be 30 ± 0.5 mm.

Specimens having the form of a regular bar of square cross section, $5 \pm 0.2 \times 5 \pm 0.2 \times 35 \pm 1$ mm in size, are used for testing. The specimens are prepared in single-socket moulds; the side subjected to the action of the punch is indicated on each specimen.

The briquetted specimens should be deburred. After sintering, the surface of the specimens is not ground. When testing, the rate of load application should be constant within a range of 4 to 10 mm per minute. Twenty specimens from each mixture batch are subjected to testing.

During the course of testing, the following sequence of operations should be observed. First of all the width and height in the middle of the specimen are measured by means of a dial gauge or micrometer gauge to the nearest 0.01 mm, then the specimens are placed on the supports so that the breaking force is applied to the side of the specimen, to which the pressure was applied during its briquetting. Then a load is applied to the middle of the specimen through the medium of the vertical punch of the device. The load must be applied, not instantaneously, but by gradually increasing it. The distance between the point of application of the force and the middle of the span should not exceed ± 0.5 mm.

8.6. Testing of Hard Alloys Used for Boring

Hard alloys for boring are subjected to various methods of inspection of their quality, including boring tests.

For this purpose, three L-shaped hard-alloy plates are soldered into casings of single-bit crowns.

The boring operation is effected on separate monoliths of abrasive rock of the sandstone or quartzite types. The rock should be uniform, without cracks or fractures; the

block mass should be not less than 0.5 ton. When testing parts 10 mm thick, boring is effected in a rock having a strength of f = 16-18 according to Prof. M. M. Protodyakonov's scale; and when testing parts 8.0 mm thick, a strength of f = 12-14.

Boring is effected by means of a telescopic percussion drill (perforator) with an energy of impact of 9 kgf·m under a pressure of compressed air of about 5 ± 0.2 atm; the length of the air-supply hose (from the pressure gauge up to the perforator) should not exceed 20 m, and the air hose should be not less than 19 mm in diameter.

In the course of testing, each crown is used for boring a bore hole 400 mm long in a rock with f = 16-18, or a bore hole 800 mm long in a rock with f = 12-14. If the hard-alloy plate breaks due to poor soldering, sharpening, or testing conditions, such a part is not taken into account, and a new part is tested.

If unsatisfactory test results are obtained with regard to even a single characteristic (density, hardness, macro- or microstructure), twice the number of specimens of the same batch of parts are tested. If unsatisfactory results are obtained when testing the bending strength of specimens or when testing parts by boring (fracture of one plate, chipping of two plates), testing should be repeated, and the test results thus obtained are considered to be final.

When examining the external appearance of hard-alloy plates, it is necessary to pay attention to chipping off and flashings of the working edges, which are not permissible. Exception is taken only with regard to certain forms, for which the depth of chipping off and flashings on the working edges should not exceed 0.2 mm; the depth of chipping off and flashings on the non-working edges of parts of all forms should not exceed 0.5 mm.

The convexity and concavity of the surface of a hard-alloy plate should not exceed 0.1 mm; for certain pieces the permissible value is 0.2 mm. The surface of the hard-alloy plate should be free of any swellings, cracks, or exfoliations.

8.7. Testing of Hard-Alloy Tips for Metal-Cutting Tools

Hard-alloy tips for metal-cutting tools are tested for their relative strength by milling them with the aid of a single-edge milling cutter. This technique is intended for testing sintered-carbide tips for metal-cutting tools by using the face-milling method. For this purpose, a single-edge milling cutter 120 mm in diameter is employed.

The milling-cutter body is made of steel. Secured mechanically in the milling-cutter body is a sintered-carbide cutting tip of 40 × 40 mm^2 cross section, the overhang of the tip from the milling-cutter body being not more than 15 mm. The geometry of the tip is as follows: rake = 12 ± ± 0.5°; plan angles = 45 ± 2.0°; clearance angle of 12 ± ± 0.5°; cutting edge back rake = 0°, and nose radius = = 1.0 mm.

Sintered-carbide tips are ground in the ordinary way. After grinding and finishing, the tips should not have any cracks or jogged edges.

The relative strength of sintered-carbide tips is tested on a carbon-steel blank. The initial dimensions of the steel blank should approximately be: cross section = 100 × × 100 mm^2, height = 120 to 130 mm. Prior to testing, the Brinell hardness of the steel blank is determined. For blanks of one group, the Brinell hardness numbers should differ by not more than 10 to 15, i.e., the diameters of the indentations should not differ from each other by more than 0.1 to 0.15 mm.

The mechanical strength of sintered-carbide plates is tested on vertical or horizontal milling machines. The machine used should guarantee rigid fixing of both the blank and tip. In the course of testing, the following measuring instruments are used: universal goniometer (for checking the rakes), a template with an optical device (for checking the nose radius), a timer (for measuring duration of testing), and a tool microscope (for determining the wear of the sintered-carbide tips after their testing).

Adopted as the criterion for tip failure is cracking or chipping on the flank by a value of 0.5 mm or larger. Each sintered-carbide tip is tested, gradually increasing the feed, star-

ting from the smallest feed and terminating with the so-called 'breaking' feed, at which the sintered-carbide tip is destroyed. The smallest feed value depends on the grade of the hard alloy; the testing schedule is given below in Table 8.6.

Table 8.6

Cutting Speeds Used when Testing the Relative Strength of Sintered-Carbide Tips on Milling

Sintered carbide	R.p.m. of milling cutter	Cutting speed, m/min	The smallest feed for starting the test		Cutting depth, mm
			mm/min	mm/cutting edge	
T5K12B TT7K12	118	44.4	37.5	0.32	1.5
T5K10	235	88.5	37.5	0.16	1.5
T14K8	300	113	37.5	0.12	1.5
T15K6	375	141	47.5	0.12	1.5
T30K4	600	226	47.5	0.06	1.0
BK8 BK6	150	56.5	30	0.2	1.5
BK6M BK4	190	71.5	30	0.16	1.5
BK2	375	141	30	0.08	1.0

The procedure for testing the strength of tips is as follows. Ten tips are selected from each batch of metal-powder products. After each feed, the tips are removed from the machine and examined under a microscope in order to determine the extent of chipping off and wear. If chipping off or cracking is less than 0.5 mm, the tips, without regrinding, are subjected to further testing, but with a greater feed (next in size), and so on until the tips are chipped off by $\geqslant$0.5 mm; whereupon they are eliminated from testing. After testing all the tips, an average 'breaking' feed is calculated from the test results, which is considered to be the strength characteristic.

CHAPTER IX

Applications of Sintered Carbides in the Metal-Working Industry

Sintered metal carbides play an important part in the industry, particularly in machine-building. The use of carbides in machine-building substantially increases the efficiency of labour, permits to attain an economy in materials and equipment, and ensures a higher production rate. In machine-building carbides are used as a material for making tools that machine metals and non-metal materials by cutting or noncutting shaping.

9.1. Principal Properties of Sintered Carbides

The field of application of carbides is determined by their physical properties, which may vary within certain limits depending on the chemical composition of the carbide and some other factors. The principal properties of carbides that determine their fields of application are hardness, strength, and plasticity. Under certain conditions the thermal conduction and coefficient of thermal expansion as well as wear resistance and cutting capability acquire a great importance.

Plasticity is the ability of a material to be deformed extensively without rupture. A great disadvantage of carbides is their poor plasticity that decreases with a reduction in the cementing phase in the carbide or, in other words, depends principally on the chemical composition of the alloy. Thanks to poor plasticity the carbides belong to the brittle alloys, that cannot endure knocks, varying loads, vibrations, and non-uniform machining allowances. With changes in temperature the plasticity of the carbides changes too. Thus at a high temperature titanium-tungsten carbides have greater resilience than tungsten carbides. This is of

great importance for cutting tools working at high temperatures. This phenomenon explains, to a certain degree, the fact that at low cutting speeds the titanium-tungsten carbides do not work so well as at high cutting speeds. The poor plasticity of carbides should always be taken into account when designing and maintaining tools and machine parts equipped with carbides.

Wear resistance is the ability of a material to withstand abrasion caused by friction of adjacent parts. Wear resistance of carbides depends mostly on the same factors as hardness and is a property almost comparable with hardness. The high wear resistance of carbides as compared with that of other materials used under the same conditions is often an irreplaceable property. Thanks to this property carbides may be used for manufacturing various types of cutting tools and machine parts and mechanisms subjected to intensive wear in service. The wear of material due to frictional contact is a result of the following phenomena:

(a) brittle shearing of particles of sliding surfaces;

(b) crushing of surfaces;

(c) chemical interaction of the rubbing surfaces of parts.

In the majority of cases all these factors act simultaneously, but usually one of these factors prevails, this depending on the chemical composition of the carbide. In general, however the wear resistance of the carbide depends on the chemical composition of the alloy, grain size of the carbide phase, and operating conditions of the tool. It is very difficult to obtain the absolute values of the wear resistance, therefore in each particular case it is determined by comparative data depending on the mode and condition of wear.

Within a single group of alloys the wear resistance will increase with an increase in carbide phase content and dispersity of carbide structure. The titanium-tungsten alloys containing a low per cent of the bonding metal, in most cases, wear out because of brittle shearing. The alloys of the tungsten group with a high content of the bonding metal wear out mainly because of the plastic deformation of the bond.

When cutting metals, the wear of carbide tools is influenced by their adhesion to the material being machined. The adhesion results from welding of chips of the machined

material to the carbide. The formed build-up is torn off the carbide together with some of its particles. As a result, the tool edge becomes very rough, intensifies the wear of carbide. Titanium-tungsten alloys have a higher wear-resistance in steel machining than tungsten alloys and a lower tendency to form craters on the tool face, because when machining steel with titanium-tungsten carbides less sticking is observed and the strength of the welded steel particles is lower. The wear resistance of titanium-tungsten carbides is higher than that of tungsten carbides.

Thermal conduction is the process of heat transfer in non-uniformly heated mediums due to which energy is transmitted between the contacting parts of a body.

Thermal conduction is an important service characteristic of carbides. Carbides rub heavily against the material being machined. As a result, heat is generated but a highly conductive material removes it from the area of contact between the carbide and the machined material. Thermal conduction greatly affects the cutting of metals with an uninterrupted chip, i.e., a chip continuously rubbing against the carbide and heating it. If the carbide has a low thermal conduction, the heat developed in the course of cutting is concentrated at the tool cutting edge and chip. In this case the chip is softened and the carbide tool is less worn out, but the cutting edge becomes very hot and wears rapidly. Therefore the thermal conduction should have a certain optimal value to ensure the best cutting properties of the carbide. Within a single group of carbides the thermal conduction depends on the amount of the carbide component and the porosity. With a reduction in the carbide phase and porosity, the thermal conduction of the carbides increases. The tungsten carbides are more thermal conductive than the titanium-tungsten ones.

Coefficient of thermal expansion is the figure which characterizes the elongation of a piece of metal in heating. Denoting the coefficient of thermal expansion as α, the length of the rod before and after heating as l_1 and l_2, respectively, and the initial and final temperatures as t_1 and t_2, respectively, it is possible to write the formula

$$\alpha = \frac{1}{l_1} \cdot \frac{l_2 - l_1}{t_2 - t_1} = \frac{\Delta l}{l_1 \Delta t}$$

The coefficient of thermal expansion of carbides depends on their chemical composition and can vary within fairly wide limits. It increases with an increase in content of the bonding metal (cobalt) and with a reduction in the carbide phase value. This may be explained by the fact that the coefficient of thermal expansion of the cementing phase is several times the value of that for the carbide phase. Expansion of carbide alloy during heating takes place because of increase in distance between each pair of adjacent atoms.

The coefficient of thermal expansion of titanium-tungsten carbides is approximately two times less than that of low-carbon steel. This difference affects the quality of carbide tips. The additional stresses due to different coefficients of thermal expansion of the carbide and steel may cause the carbide tip to break off over the entire area of brazing. In service care is taken to avoid such a trouble (for example, by using permalloy spacers between the tip and holder). The thermal properties of carbides are important both for making and using the tools. Carbides are very sensitive to heating and cooling which are unavoidable in brazing carbide tips to holders and in grinding carbide parts. To avoid cracking of carbides slow heating is used in brazing, and easier cutting conditions for grinding and sharpening, with abundant cooling. Cracks in carbides may also appear in conditions of rapid local heating when cutting, especially with heavily worn cutting faces. Therefore a large wear of tools is not permitted.

Red hardness is the property of carbides of retaining hardness, wear resistance and other qualities required for effective cutting action at high temperatures. Red hardness of carbide is of great importance because with its increase the cutting speed and the production rate may be increased. This quality of cemented carbides is also of great importance when cutting steels because, as mentioned above, the continuous chip produced constantly rubs against the carbide tip and heats it up.

The red hardness is determined by the strength of the carbide at high temperatures. The bonding metal (cobalt) is not so strong at high temperatures as the carbides of refractory metals such as tungsten and titanium. It follows that the red hardness of sintered metal carbides depends

on the contents of the cementing metal and the carbides. Red hardness manifests itself in the range of 900 to 1100°C, being higher for titanium-tungsten carbides than for tungsten carbides due to the presence of titanium carbide.

The properties of the carbides considered previously influence their fields of application. Table 9.1 specifies the principal grades of carbides made in the Soviet Union, their chemical composition, principal characteristics and applications. Three groups of sintered carbides are available:

(1) tungsten or tungsten-cobalt carbides (WC-Co). Alloys of this group are denoted by letters BK followed by a figure that indicates the percentage of cobalt in the alloy. Thus, BK6 denotes an alloy of 6 per cent cobalt and 94 per cent tungsten carbide. Coarse-grained carbides of this group have an additional letter B (for example, BK8B), fine-grained alloys, letter M (for example, BK6M);

(2) titanium-tungsten carbides (WC-TiC-Co). Carbides of this group are denoted by letters TK, followed by a figure indicating the cobalt content, as before, while a figure after letter T is the percentage of titanium carbide. Thus, T5K10 alloy contains 10 per cent cobalt, 5 per cent titanium carbide and 85 per cent tungsten carbide;

(3) titanium-tantalum-tungsten carbides (WC-TiC-TaC-Co). These alloys are denoted by the same letters as the titanium-tungsten alloys but with an additional T (for example, TT7K12). The figure following the letters TT indicates the approximate total content of carbides of titanium and tantalum. The figure following the letter K indicates the cobalt content. The variety of carbides is due to the diverse applications of these alloys.

9.2. Metal Cutting

Modern engineering is based on mass production of various machines. The production of a large quantity of similar machines requires a manufacturing process that ensures accurate reproduction and interchangeability of components. Mass production of identical components and their reproduction always with the same accuracy is only possible when the tool is capable of maintaining its shape and dimensions, i.e., has sufficient wear resistance.

Table 9.1

Main Grades of Carbides Made in the USSR. Composition. Principal Properties. Conditions for Use

Grade of alloy	Approximate composition, %				Physical properties				Service conditions	Conditions for use
	WC	TiC	TaC	Co	ultimate bending strength, kgf/mm², not less than	hardness *HRA*, not less than	density, g/cm³	ultimate compression strength, kgf/mm²		
					Tungsten carbides					
BK2	98	—	—	2	110	90	15.0 to 15.4	416	Extremely high wear resistance and the highest permissible cutting speed. Moderate service strength, resistance to impacts, vibrations, and crumbling-out	Finishing, semifinishing and finishing with a small shearing section (diamond-type machining) turning with uninterrupted cut; final thread cutting, hole reaming and other similar machining operations for cast iron, non-ferrous metals and their alloys and non-metal materials, as well as hardened steels. Wet drawing of wire made of steel, non-

										ferrous metals and their alloys
BK3	97	—	—	3	100	89	15.0 to 15.3	—	Extremely high wear resistance. Moderate service strength and resistance to crumbling-out.	Cutting of sheet glass
BK3M	97	—	—	3	110	91	15.0 to 15.3	—	Extremely high wear resistance due to fine-grained structure. Moderate service strength, resistance to impact, vibrations, and crumbling-out. Higher wear resistance as compared to BK2 carbide when machining grey cast irons	Finishing, semifinishing and finishing with a small shearing section (diamond-type machining) machining grey cast iron, carbonized and hardened steels (alloyed and carbon) as well as very hard cast irons. Wet drawing of wire made of steel, non-ferrous metals and their alloys. For tools and parts operating under intensive abrasive wear conditions
BK4	96	—	—	4	135	89.5	14.9 to 15.1	441	High wear resistance and service strength. Good resistance to impacts, vibrations, and crumbling-out. Service life is 1.5 to 2.5 times longer than for BK6 carbide and 2 to 4 times	Rough turning with non-uniform shearing section and uninterrupted cut; rough and finish milling, boring and drilling of normal and deep holes; rough counterboring. Cutting off by lathe

Continued

Grade of alloy	Approximate composition, %				Physical properties				Service conditions	Conditions for use
	WC	TiC	TaC	Co	ultimate bending strength, kgf/mm², not less than	hardness *HRA*, not less than	density, g/cm³	ultimate compression strength, kgf/mm²		
									longer than for BK8 carbide	tools when machining cast iron, non-ferrous metals and their alloys, non-metal materials, titanium and its alloys as well as stainless and heat-resistant steels and alloys
BK4B	96	—	—	4	140	88.0	14.9 to 15.1	—	Wear resistance lower than for BK4 carbide due to coarser grain. Service strength, resistance to impacts, vibrations, and crumbling-out are higher than that for BK4 carbide	Boring of coals, anthracites, quartz shists, potash and rock salts, and other rocks of uniform structure with electric and pneumatic drills. Boring of weak rocks (hardness up to 8) by hand and column electrical drills
BK6M	94	—	—	6	135	90.0	14.8 to 15.1	—	Wear resistance is higher than that for BK6	Finishing and semifinishing heat-resistant

									carbide due to finer grain; service strength, resistance to impacts, vibrations, and crumbling-out are somewhat lower. Is superior to BK4 and BK6 carbides in machining grey cast irons	steels and alloys, austenite stainless steels, special hard cast irons including chilled ones, and hardened cast irons, hard bronze, alloys of light metals, hard and abrasive insulation materials. Machining raw carbon and alloyed steels with thin shearing sections at low cutting speeds
BK6	94	—	—	6	145	88.5	14.6 to 15.0	460	High wear resistance and moderate cutting speed (less than that for BK2 and BK4 grades). Higher service strength and resistance to impacts, vibrations, and crumbling-out than for BK2 and BK3M grades	Rough turning with uninterrupted cut; finishing and semifinishing turning with interrupted cut; rough thread cutting with lathe tools; thread cutting with rotating heads; semifinishing and finishing milling of continuous surfaces; boring of preliminary drilled holes. Dry drawing of wire made of steel, non-ferrous metals and their alloys. For rapidly wearing parts of machines, fixtures and tools

Continued

Grade of alloy	Approximate composition, %				Physical properties				Service conditions	Conditions for use
	WC	TiC	TaC	Co	ultimate bending strength, kgf/mm², not less than	hardness *HRA*, not less than	density, g/cm³	ultimate compression strength, kgf/mm²		
BK6B	94	—	—	6	150	87.5	14.6 to 15.0	—	Wear resistance is lower than that for BK6 grade due to coarser grain; service strength, resistance to impacts, vibrations, and crumbling-out are higher than those for BK6 grade	Percussion-rotary drilling of weak rocks (hardness up to 8). Cutting hard pit coal with small- and medium-sized inclusions of hard rocks; drilling with rolling cutter bits
BK8	92	—	—	8	160	87.5	14.4 to 14.8	447	Higher service strength and resistance to impacts, vibrations, and crumbling-out than those for BK6 grade; lower wear resistance and permissible cutting speed	Rough turning with non-uniform shearing section and interrupted cutting; planing; rough milling; drilling; rough boring and drilling of cast normal and deep holes; rough counterboring, reaming and other similar machining opera-

										tions of cast iron, non-ferrous metals and their alloys, and non-metal materials. Machining of tough heat-resistant steels and alloys. Drawing and sizing of steel rods and pipes, non-ferrous metals and their alloys. Rapidly wearing parts of machines, fixtures, and tools including stamping tools operating under small impact loads. Rotary boring with cutting tool for exploration and oil wells in weak rocks (hardness up to 8) of low abrasive capacity but the production rate is lower than that for BK4B grade. Sawing of marble and limestone blocks
BK8B	92	—	—	8	170	86.5	14.4 to 14.8	390	Wear resistance is lower than that for BK8 grade due to coarser grain; service strength, resistance to impacts, vibrations, and crumbling-out are higher than those for BK8 grade	Drilling with rolling cutter bits, percussion-rotary and rotary drilling of hard rocks (hardness up to 8). Cutting coals with large inclusions of hard rocks. Machining very hard stones. Drawing of steel rods and pipes with increased reduction

Continued

Grade of alloy	Approximate composition, %				Physical properties				Service conditions	Conditions for use
	WC	TiC	TaC	Co	ultimate bending strength, kgf/mm², not less than	hardness *HRA*, not less than	density, g/cm³	ultimate compression strength, kgf/mm²		
BK10	90	—	—	10	160	87.0	14.2 to 14.6	417	Service strength, resistance to impacts and vibrations are higher than those for BK8 grade; wear resistance is lower	Drawing of steel rods and pipes. Rapidly wearing parts of machines, fixtures and tools
BK15	85	—	—	15	180	86.0	13.9 to 14.1	366	Service strength, resistance to impacts, vibrations, and crumbling-out are higher than those for BK8 grade; wear resistance is lower	Boring with sinking drills, percussion-rotary drilling of hard rocks and percussion-rotary drilling with hydraulic percussion machines; production rate is lower than that of BK8B grade. Percussion facing of granite. Drawing of steel rods and pipes with large reduction. Rapidly wea-

										ring parts of machines, fixtures, instruments and tools including stamping tool operating under small impact loads. Cutting tool for woodworking; drilling with rolling cutter bits
BK20	80	—	—	20	190	84.5	13.4 to 13.7	350	Service strength, resistance to impacts, vibrations, and crumbling-out are higher than those for BK15 grade; wear resistance is lower	Rapidly wearing parts of machines, fixtures, instruments and tools including stamping tool operating under medium impact loads
BK25	75	—	—	25	200	83.0	12.9 to 13.2	330	Service strength, resistance to impacts, vibrations, and crumbling-out are higher than those for BK20 grade; wear resistance is lower. Has some plasticity	Rapidly wearing parts of machines, fixtures, instruments and tools including stamping tool operating under great impact loads
							Titanium-tungsten carbides			
T30K4	66	30	—	4	90	92.0	9.5 to 9.8	—	The highest wear resistance and cutting speed for titanium-tungsten carbides with reduced service strength and resistance to impacts, vibrations, and crumbling-out	Finishing turning with a small shearing section (diamond-type machining); thread cutting and hole reaming in parts made of raw or hardened carbon oralloyed steels

Continued

Grade of alloy	Approximate composition, %				Physical properties				Service conditions	Conditions for use
	WC	TiC	TaC	Co	ultimate bending strength, kgf/mm², not less than	hardness *HRA*, not less than	density, g/cm³	ultimate compression strength, kgf/mm²		
T15K6	79	15	—	6	115	90.0	11.0 to 11.7	390	High wear resistance and cutting speed, but lower than for T30K4 grade. Service strength, resistance to impacts, vibrations, and crumbling-out are higher than those for T30K4 grade	Rough and semifinishing turning with uninterrupted cut; finishing turning with interrupted cut; thread cutting with lathe tools and rotary heads; semifinishing and finishing milling of continuous surfaces; boring of holes preliminarily drilled; finishing counterboring, reaming and other similar types of machining of carbon and alloyed steels
T14K8	78	14	—	8	125	89.5	11.2 to 12.0	420	Service strength, resistance to impacts, vibrations, and crumbling-out	Rough turning with non-uniform shearing section and uninterrup-

									are higher than those for T15K6 grade; wear resistance and permissible cutting speed are lower	ted cut; semifinishing and finishing turning with interrupted cut; rough milling of continuous surfaces
T5K10	85	6	—	9	135	88.5	12.3 to 13.2	460	Service strength, resistance to impacts, vibrations, and crumbling-out are higher than those for T14K8 grade; wear resistance and permissible cutting speed are lower	Rough turning with non-uniform shearing section and interrupted cut; shape turning; cutting-off with lathe tools; finishing planing; rough milling of interrupted surfaces and other types of machining carbon and alloyed steels mainly in the form of stampings, forgings and castings; cutting tough skin and scale
T5K12B	83	5	—	12	160	87.0	12.8 to 13.3	—	Service strength, resistance to impacts, vibrations and crumbling-out are substantially higher than those for T5K10 grade; wear resistance and permissible cutting speed are lower. As compared with tools of high-speed steel it permits the cutting speed to be at least doubled retaining the size of shearing section	Heavy rough turning of steel forgings, stampings and castings to remove the skin with cavities, sand, slag and non-metallic inclusions; cut being accomplished with non-uniform shearing section and impacts. Operation on worn equipment as well as working of wheel pairs with heavy worn areas. All types of planing of carbon and alloyed steels. Drilling of holes in steel

Continued

Grade of alloy	Approximate composition, %				Physical properties				Service conditions	Conditions for use
	WC	TiC	TaC	Co	ultimate bending strength, kgf/mm², not less than	hardness *HRA*, not less than	density, g/cm³	ultimate compression strength, kgf/mm²		
Titanium-tantalum-tungsten carbides										
TT7K12	81	4	3	12	160	87.0	13.0 to 13.3	—	Service strength, resistance to impacts, vibrations, and crumbling-out are substantially higher than those for T5K10 grade; wear resistance and permissible cutting speed are lower. As compared with tool of high-speed steel it permits to increase cutting speed not less than two times retaining the size of shearing section. This grade has a somewhat higher service strength than T5K12B grade	Heavy rough turning of steel forgings, stampings and castings with tough skin, parts including cavities, sand, slag and different non-metallic inclusions, cut being accomplished with non-uniform shearing section and impacts. Operation on worn equipment as well as working of wheel pairs with heavy worn areas. All types of planing of carbon and alloyed steels. Heavy rough milling carbon and alloyed steels
TT10K8B	82	3	7	8	140	89.0	13.5 to 13.8	—	High service strength and resistance to impacts and vibrations with moderate wear resistance	Rough and semifinishing machining of some grades of tough materials including heat-resistant steels and alloys

Of all available and comparatively inexpensive materials sintered metal carbides have the greatest wear resistance, being second only to diamond. The introduction of sintered metal carbides has considerably increased the tool life, permitted higher feeds and speeds and raised the production rate, and improved the quality of machining.

Carbides are very widely employed in metal cutting. The metal cutting process (machining) consists in removing a layer of metal from the blank to obtain a machine part of the required shape and dimensions, and with the specified level of surface finish. Machining is accomplished in metal-cutting machines by means of cutting tools so designed as to procure the accuracy of the shape of the machined part, precision of dimensions, good quality of surface finish, high production capacity, high-wear resistance, high-strength, technological effectiveness of design, economic service, and low cost.

Metal cutting tools are divided into the following main types: (1) single-point tools, (2) milling cutters, (3) tools for machining of holes.

Single-point tools are the most widely used cutting tools. They are employed in various machines such as lathes, shaping machines, slotting machines, etc. Single-point tools may be subdivided into lathe tools, shaper-and-planer tools, slotting tools, etc., and according to mode of machining into bull-nose tool, cutting-off tools, etc. According to the nature of their work they are classified as roughing, finishing, and shaving tools. By shape of the stem cross-section the tools are divided into square, circular, and rectangular, and by the head design into straight, hook, cranked, etc.

Milling cutters are also extensively used and are the most productive tools. There is no other tool that has such a wide variety of shapes, types, and uses as the milling cutter. With milling cutters it is possible to machine planes, shaped surfaces, etc.

Hole machining tools. The most widely used tools for this purpose are: drills, counterbores, and reamers. There are many types, designs and shapes of these cutting tools, by means of which it is possible to drill holes in solid materials, enlarge drilled holes, drill into conical recesses, and make precise holes, etc.

There are also other types of tools which play an important part in metal cutting such as pull and push broaches, thread making tools (taps, dies, etc.), gear-making tools, and abrasive tools.

Although there is a great variety of groups, shapes, and sizes of cutting tools, they have many common geometrical and design parameters.

From the point of view of design, each metal-cutting tool consists of two main parts: the working part that directly contacts the workpiece and effects the cutting process, and the body or mounting element by which the tool is secured in the machine. Sintered metal carbides are used mainly as working parts of the tools.

A metal-cutting tool fitted with a carbide tip differs from a tool made of tool steel. This difference is due to the inherent physical and service properties of carbides such as hardness and wear resistance, high red-hardness, sensitivity to impacts and vibrations, etc.

Carbide cutting tools should meet the following requirements:

(1) sufficient rigidity of design,

(2) reliable securing of the carbide tip to the tool holder,

(3) use of mechanical fixing of carbide tips to holders,

(4) proper selection of shape and size of carbide tips,

(5) correct selection of geometrical parameters of the working part of the tool,

(6) case of manufacture which facilitates efficient methods of working.

The required rigidity of carbide tool design is ensured by providing holders of maximum permissible sizes and using high strength heat treated steels.

The reliable fastening of the carbide parts is ensured by selection of the holder design suitable for mechanical fixing of the articles. For these purposes recesses are provided in which under the action of cutting forces carbide part is pressed against the tool body.

The most widely used method of fixing the tips to the tool shank is brazing.

The carbide tips are fixed by means of brazing solders, fluxes, and compensating spacers. The solders used for brazing carbide tips are given in Table 9.2.

Table 9.2

Metals Used for Brazing Carbide Tips

Brazing metals	Content, per cent						Melting points, °C	Use
	Cu	Ni	Al	Mn	Zn	Ag		
Copper-nickel	70	30	—	—	—	—	1220	For tools working with heavy loads, tips heated to 900°C
German silver	68.7	27.5	0.8	—	3	—	1170	
Electrolytic copper	99.9	—	—	—	—	—	1083	Ditto, tips heated to 700°C
Aluminium-nickel	Balance	3-4	0.4-0.6	1.5-2.5	—	—	1050	
Brass-nickel	68	5	—	—	27	—	1000	
Brass Л68	70	—	—	—	30	—	950	For tools working at medium loads, tip heated to 600°C
Brass Л62	62	—	—	—	38	—	900	
Manganese-nickel	62-68	4-5	—	1.5-2	Balance	—	930	
Silver ПСр10	53	—	—	—	37	10	850	For brazing of T30K4, BK2, BK3M carbides
Silver ПСр45	30	—	—	—	2	45	725	

Table 9.2 shows that the solder to be used is determined by operating conditions of the tool and the grade of carbide. The melting point of the brazing metal must be about 300°C higher than the temperature produced by cutting action. In the process of cutting the brazing metals maintain their strength, and plasticity, while their thermal conduction ensures rapid removal of heat from the tip to tool holder.

The flux is used for protecting the brazed surfaces against oxidation and to facilitate removal of oxides. Besides, it contributes to the wetting of the brazed surfaces and to spreading of the solder. The flux compositions recommended for brazing of carbide tips are given in Table 9.3.

Table 9.3

Flux Content, Recommended for Brazing of Carbide Tips

Flux content, per cent			Melting point, °C	Use
sodium tetraborate (borax)	boracic acid	calcium fluoride		
70	20-22	8-10	620	For all brazing metals
50	50	—	577	For brazing with brass
—	57	43	600	For brazing with silver
100	—	—	741	For all brazing metals when other fluxes are unavailable

To reduce thermal stresses when brazing thin and long tips, as well as large tips working under heavy stresses and also when brazing carbides with a large content of titanium, compensating spacers made of low-carbon steel or iron-nickel alloy (permalloy) are used. These spacers improve the quality of the seam, increase the adhesion strength and substantially reduce the stresses that appear when the tool cools down after brazing.

Carbide tips are brazed to the holders by the following methods: (1) induction, by high-frequency currents (hf), (2) contact, with electric butt welding apparatus, (3) in

a furnace, in fired and muffle furnaces, (4) gaseous, by means of an oxyacetylene torch.

Of all the above listed methods the most effective and reliable method is h.f. brazing. For all methods it is necessary to pay attention to proper brazing conditions, especially to the heating and cooling of the tool, since rapid heating and cooling may result in cracking of carbide tips.

When making the carbide tools the bearing faces of the connecting parts and carbide tips should tightly fit one

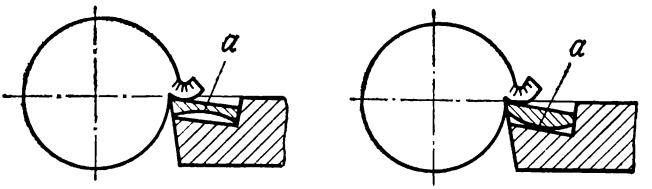


Fig. 9.1. Possible cases of destruction of tips in machining due to distortion
a — place of destruction

another. Distortion may cause the destruction of the tips during the cutting process (Fig. 9.1). The shape and sizes of the recesses in the tool holders for carbide tips should correspond to the shape and sizes of the tips.

However, the method of carbide tip brazing to the connecting part of the tool has several disadvantages, the main one being the difference in the linear expansion coefficients of the steel of the connecting part and of the carbide tip (thermal coefficient of linear expansion for carbides is half of that for structural carbon steels).

With non-uniform cooling of the brazed-on tool carbide tips may crack as a result of additional stresses. This reduces the strength of the tips and leads to intensive crumbling and destruction in the course of operation.

Besides, the amount of steel used for making the connecting parts of the tool (for example, tool holders) and their manufacturing cost are great.

In recent years, the industry has began to make use of mechanical fastenings for joining the carbide tips to the connecting parts of the tools (single-point tools, milling cutters and others). For this purpose the carbide industry

has developed the manufacture of polyhedral throw-away tips.

Fig. 9.2 shows the design of mechanically fastened polyhedral carbide tips. There are also other tool designs with mechanical fastening of tips.

The mechanical fixing of tips has a number of advantages as compared with the brazing method: reliability in operation, compactness, ease of maintenance, simplicity of design, durability of holders, economy in tool cost.

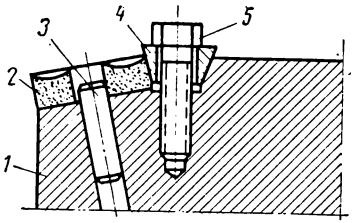


Fig. 9.2. Diagram of tool design with mechanical fastening of polyhedral carbide tips

1 — holder; *2* — polyhedral carbide tip; *3* — locking pin; *4* — wedge; *5* — bolt

The main factors to be considered in cutting are feeds and speeds, and the tool geometry. The feeds and speeds depend on the required accuracy and surface finish of the component, the rigidity of the system, and the most efficient use of the machine and cutting tool. When selecting cutting conditions with given machining conditions the depth of cut, number of passes, the feed value, and the cutting speed are determined for the permissible cutting force and power.

The geometry of the tool includes the shape of the cutting part of the tool and its sharpening angles. The geometry of a carbide tool depends on the working conditions: which are here the properties of the material to be machined, the type of machining, the width and thickness of the layer to be removed, the cutting speed, and nature of the tool wear. The correct choice of these parameters determines the production rate, cutting capacity, quality of machining and tool life.

In cutting, the working part of the tool is subjected to a number of physical effects; friction against the material

being machined, impacts, and heating produced by the friction. The higher the ability of the carbide to withstand these effects the longer the tool life.

Various materials behave differently during machining; for example, when cutting steels a continuous chip is produced which rubs against the cutting part of the tool all the time, but when cutting cast iron or brittle non-ferrous metals the tool is mostly subjected to impact load because the chip is brittle and is continuously sheared off. Therefore in machining steel the wear resistance of the cutting part of the tool and its working ability at high temperatures are of great importance. In machining cast iron and brittle non-ferrous metals the cutting part should have great strength.

The three groups of sintered metal carbides discussed previously differ in physical properties and are used for various cutting conditions. For example, high-strength tungsten-cobalt alloys are employed in conditions of shock loads, e.g. for machining cast iron and brittle non-ferrous metals. High-speed machining of steel is carried out with titanium-tungsten alloys because alloys of this group have a high wear resistance and better cutting properties at high temperatures. The heat generated during the cutting process is concentrated at the cutting edge of the tool and this facilitates the softening of the chip and makes the operation of the cutting tool more effective.

When machining steel at low cutting speeds and there are no high temperatures at the cutting edge some of the tungsten-cobalt alloys may be used.

When machining steels titanium-tungsten alloys have a better wear resistance than tungsten-cobalt alloys and therefore a smaller tendency to pitting the front face of the cutting tool which may further lead to crumbling of the cutting part under pressure of the chip. This is explained by the reduced adhesion and strength of welded steel particles machined with titanium-tungsten alloys. In such conditions the tungsten cobalt alloys are subjected to more intensive wear. As a result of chips adhesion in the cutting process, irregularities are formed on the contact surfaces, the welded chip being torn off together with carbide particles; therefore the cutting edges become more irregular and this intensifies the wear of carbide.

As compared with other cutting tool materials carbides improve the productivity because of a higher cutting speed and a longer tool life. With carbide tools it is also possible to cut materials not otherwise able with any other tool. In recent years the field of application of carbides in metal working has greatly expanded. Carbides are now beginning to be used for cutting plastics, glass, wood and other materials.

9.3. Noncutting Shaping

Noncutting shaping of metals is a tremendous field of metal working, which includes drawing, cutting, punching, extrusing, bending, upsetting etc., The effective application of sintered carbides in this field is of the same importance as in metal cutting.

The long service life of carbide tools for drawing and stamping ensures an increase in production rate and higher stability of dimensions of the parts being worked, permits the use of these tools in transfer lines, and requires a smaller quantity of duplicating tools. The service life of a carbide tool for noncutting shaping is 20 to 100 times longer than that of a tool made of steel. However, carbides are not so widely used for noncutting shaping as for metal cutting. This is explained by the fact that carbides for this kind of working began to be used much later than in metal cutting, because suitable carbides for this purpose were recently produced. There was also no equipment available for working the carbides used in noncutting shaping.

The adequate carbides for noncutting shaping of metals must be chosen according to the particular operating conditions, and the effective utilization of carbides for this purpose depends largely on the quality of the equipment in which the carbide tool is used. Thus, for example, carbide dies have a considerable advantage over steel dies only when used in high-quality pressing equipment with careful maintenance of the dies, and due attention to preparation of the material to be stamped. The design of carbide processing equipment for noncutting shaping of metals differs from analogous steel working equipment and it should ensure: minimum use of carbide, adequate carbides and attachment

fixtures, rigid design, stable and correct arrangement of tool working elements. Only those working parts of the tool that are directly involved in working the metal are fitted with carbide inserts. The working parts are attached to the steel bodies in three different ways: (1) by brazing; (2) by pressing in and (3) by mechanical fixtures (screws, pins, wedges, rings, etc.).

Brazing is the simplest and most efficient method of fixing the carbide inserts which ensures maximum economy of carbide and labour.

The surfaces to which the carbides are brazed, should be ground. Brazing as a rule is accomplished by high-frequency

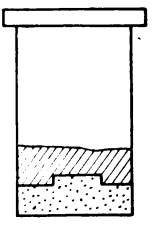


Fig. 9.3. Circular punch with brazed-on carbide insert

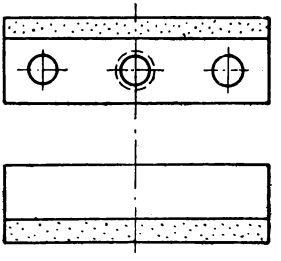


Fig. 9.4. Die section with brazed-on carbide knife

current techniques. The brazing solders used are the JI62 and JI68 brasses and sometimes an aluminum-manganese solder. Flux is used to protect the carbide insert and steel body from becoming oxidized. Some of the working die parts with brazed carbide inserts are shown in Fig. 9.3 and 9.4.

The pressing-in of carbides into their steel holders, used mainly for cylindrical carbides, is done in hydraulic presses with the carbides either heated or cold and given a certain interference. This interference is determined in accordance with the forces applied to the insert. Thus, for example, the interference is 0.2 to 0.4 per cent of the outside diameters of the inserts for punching dies, 0.3 to 0.5 per cent for drawing dies and 1 to 1.5 per cent for upsetting dies.

Large interferences can be obtained by taper pressing

with an angle equal to 1.5 to 3°. A carbide insert pressed in with a taper is shown in Fig. 9.5.

To avoid the destruction of carbide inserts while pressing them in and working in service the wall thickness should

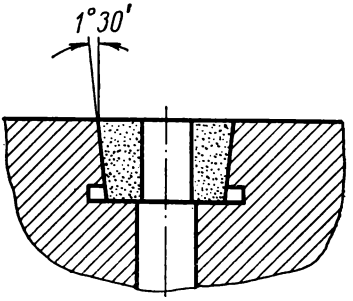


Fig. 9.5. Carbide insert pressed on taper

range from 8 to 15 mm. The inserts should adjoin the body uniformly at all points. For this purpose they are ground before being pressed in. There are several methods of fixing the carbide inserts, two of them are shown in Fig. 9.6.

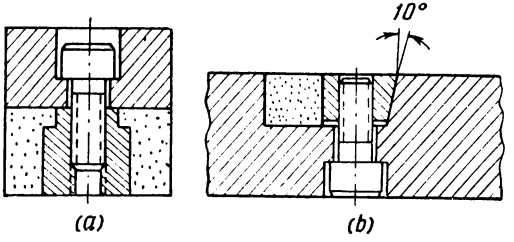


Fig. 9.6. Fastening of carbide inserts
(*a*) by screw and bush; (*b*) by wedge

The production of carbide components used in noncutting shaping of metals depends on the required shape and accuracy of the part. Usually the parts are ground but sometimes treated by electrophysical and electrochemical methods. If the carbide parts are made from plasticized or semi-sintered carbide blanks both mechanical and manual methods are used. The tools in this case are the same as for machining

of steel articles (single-point tools, milling cutters, drills, etc.).

The selection of a carbide for a particular method of noncutting shaping is determined by several factors the more important of which are operating conditions, properties of the material to be worked, and the service properties of the carbide. The various processes of noncutting shaping are discussed further.

Drawing is a process in which a wire, bar stock or tubing is drawn through the hole of a special tool, the drawing die, the hole being somewhat smaller in size than the initial material. As a result of drawing the cross section of the part is decreased and the length increased. This process is widely used in the manufacture of rods, wires, tubes, pipes, etc.

Drawing is performed in powerful drawbenches which consist of two main component parts: the drawing die and pulling unit.

Drawing is one of the first fields of application of carbides in noncutting shaping of metals. Carbide drawing dies have now almost entirely replaced steel dies. The advantage of a carbide drawing die as compared with those made of steel is its high dimension retaining capability. This enables to obtain a uniform cross section of the worked material over its entire length and to carry out the drawing at high speeds. The application of carbide drawing dies also improves the surface finish.

The drawing operation is characterized by a high specific pressure exerted on the working surface of the tool, great friction and absence of impact loads on the tool. Thus, the tool designed for metal drawing must have a high resistance to plastic deformation, tensile forces and to friction. Service properties of carbides and plant experience have shown that for drawing work the tungsten group of carbides (BK2, BK3M, BK6, BK8, BK10, BK15) are the best, the exact grade being selected for the concrete conditions of drawing. These conditions include the properties of the material to be worked, the medium in which the drawing takes place (dry or wet), the shape and dimensions of the cross-section of the material to be drawn, its reduction, etc. Before beginning to draw a series of articles of new material and shape, experimental work is carried out to select the

optimal carbide grade and the adequate geometrical parameters for the drawing die hole, which are of great importance for efficient work.

The die hole is divided into four zones (Fig. 9.7): lubricating *1*, deforming *2*, sizing *3* and outlet *4*, each having a certain function, for example, in the deforming zone, the cross-sectional dimensions of the material are reduced.

The dimensional durability of carbide drawing dies greatly depends on their density. Therefore, when drawing products

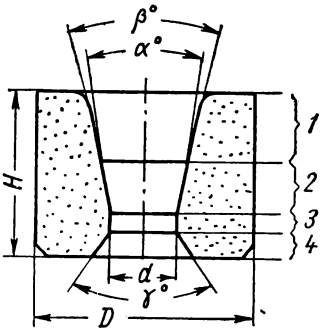


Fig. 9.7. Cross section of a rod or wire drawing die

of large cross section (pipes, bars, etc.), the drawing dies are produced by hot pressing thus ensuring the production of high density dies of large sizes. The carbide die is pressed into a steel yoke, dead ended.

Pressworking is one of the extensively employed methods of noncutting shaping of metals (by means of presses or hammers) in which a metal blank is pressed in a closed die to obtain a part of predetermined size and shape. Cold and hot pressworking are the two methods used; in the latter case the metal is preheated. The high production rate and identical shapes and sizes of the pressed articles have contributed to an extensive use of pressworking in mass production. So far, carbides have not been widely employed in hot pressworking though some experimental work is in progress.

In recent years, extensive use has been made of carbide inserts for the working elements (punches and dies) of punching, drawing, bending and upsetting dies.

There is a large group of dies performing severing operations (cutting off, punching out, piercing, etc). Their nomenclature is especially large in the electrical industry where a great deal of electrical steel punchings are made (III-shaped, II-shaped, etc.) for electric motors and transformers. Electric steels have a high silicon content and are very hard; this results in a sharp reduction of die service life. On the average, steel dies for punching electric sheet steels require resharpening after 10,000 to 15,000 punches whereas their service life may be increased 30 to 50 times by providing them with carbide inserts. Carbide dies are widely used for punching electric steels up to 0.5 mm thick and sheet carbon steels (grade 45 and softer) up to 3 mm thick.

Carbide punching dies differ from steel ones in design because of the specific properties of carbides. The main distinctions are their more rigid construction (greater thickness of die plates and punch holders, larger diameters of guide columns, reduced overhang of punches, etc.) and more accurate aligning of the cutting elements during the service period of dies.

In service of the punching dies their cutting elements (male and female dies) equipped with carbide inserts are subjected to systematic impact loads, therefore the use of highstrength tungsten-cobalt carbides are recommended. The punches in service are subjected to higher loads than the dies, therefore carbides of higher strength are used in their manufacture.

Depending on the overall dimensions of the punchings and their shapes the dies may be of the single-piece or built-up design. Punches are also made either entirely of carbides or some parts are fitted with them. Carbide inserts are fixed to their steel parts by brazing, pressing or mechanical means.

The industry widely uses drawing and bending dies by means of which an extensive range of parts designed for various branches are produced. During the operations the working parts of the drawing dies are greatly affected by the material being pressed and therefore become greatly worn out. High temperatures and pressures (up to 50-80 kgf/mm^2 when drawing with thinning) also develop therefore the particles of the workpiece material often stick to the steel

working parts of the die and make scratches on the workpiece. The use of carbide almost entirely excludes this phenomenon and the tool life is increased 50 to 100 times.

Carbide inserts fail in drawing and bending operations because of worn working parts of die due to friction between

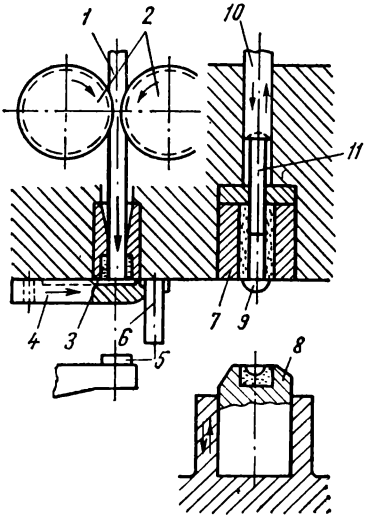


Fig. 9.8. The cold heading principle

1 — metal bar stock; *2* — feeding rollers; *3* — cutting-off die; *4* — knife; *5* — adjusting stop; *6* — blank; *7* — heading die; *8* — heading punch; *9* — headed part; *10* — ejector; *11* — ejector rod

the work material and the carbide parts and destruction of carbide inserts when the high pressures are applied.

Heading is a noncutting operation which has found a wide application in the mass production of small parts and fastenings (bolts, screws, nuts, rivets), balls and rollers for bearings, etc. Cold heading in one or several strokes is done chiefly in special automatic cold headers in which all operations, including bar (or wire) feed, cut-off, carryover and ejection of the finished parts are completely automatic. In the course of heading the material is subjected to plastic deformation and changes its shape.

The working parts of an automatic cold header equipped with carbide inserts and the operation sequence of the tool are illustrated in Fig. 9.8. The carbide inserts are fitted into the cutting-off dies, knives, heading dies and punches, that take up the entire load required for changing the shape

of the article being headed. Carbide inserts used in the heading process should have tensile strength and wear resistance to ensure dimensional stability of the worked parts for a long period. Besides, they should withstand large impact loads. Usually the carbide heading tools fail because of cracks in the carbides or because of wear. The investigations carried out and production practice show that the

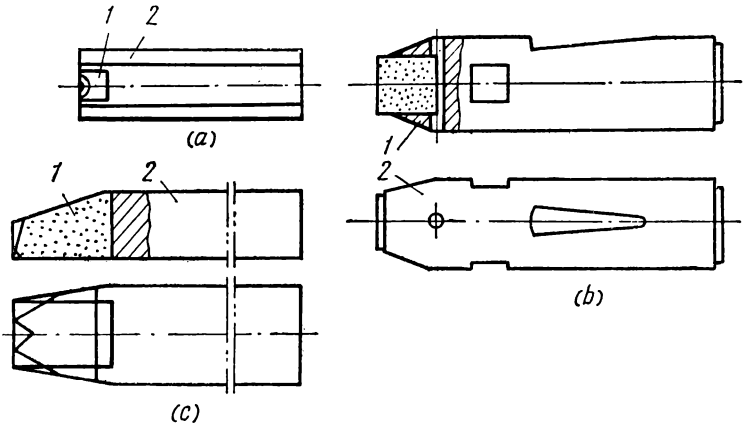


Fig. 9.9. Carbide tool used in nail automatic cold headers (*a*) die; (*b*) punch; (*c*) knife; *1* — carbide inserts; *2* — bodies

best tool materials for heading operation are the carbides with a high cobalt content, such as grades BK15, BK20 and sometimes BK25.

Cold heading of nails in high-capacity wire nail automatic cold headers has become wide-spread. Their output is from 400 to 900 nails per minute depending on size. One of the ways to increase the output of nails is to prolong the tool service life. This will substantially increase the production rate due to reducing down-time for tool changing. The use of carbides in the manufacture of nail tools has become the most effective method for making tools more durable.

In tools equipped with carbide inserts the BK20 carbide has shown the highest wear resistance in nail production. The service life of tools with carbide inserts exceeds the life of steel tools 15 to 60 times. A nail tool provided with carbide inserts is shown in Fig. 9.9.

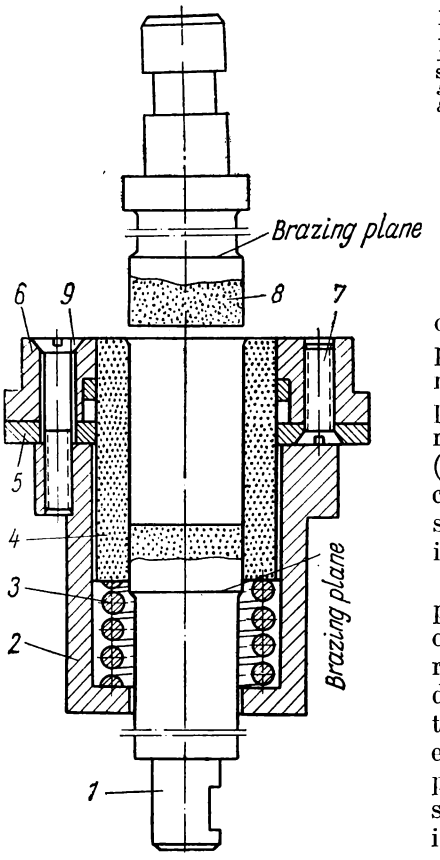


Fig. 9.10. Press mould for pressing piezoelements

1 — lower built-up punch; *2* — sleeve; *3* — spring; *4* — die; *5* — base; *6* — flange; *7* — screw; *8* — upper punch; *9* — screw

Moulding is a method of compacting materials, powders, and powdered mixtures including metal powders. Moulding is carried out in press moulds (or dies) whose working cavities determine the shapes and sizes of the items being compacted.

Large scale and mass production of parts made of highly abrasive materials takes place nowadays on a large scale in the radio engineering and electronic industries. The production of articles of sintered metal carbides is also based on pressing powders in special dies.

If the working parts of dies are provided with carbides they increase their wear-resistance 60 to 100 times and facilitate the automation of the pressing process.

The carbide moulds fail in service because of abrasive wear, therefore they are equipped with BK6M, BK6, BK8 carbides. Carbide dies are extensively employed for moulding ferritic iron articles, in tube drawing and pressing of various electrovacuum ceramic articles and glass mass, when moulding carbide components, etc.

Depending on the shape and size of the pressed articles the working parts of dies are either made entirely of carbide or provided with parts made of it. The carbide parts are secured to the steel bodies by brazing, by pressing in or by a mechanical fixture. The design of a mould fitted with carbide inserts used for pressing piezoelements is shown in Fig. 9.10.

Sintered metal carbides are used not only for fitting to the tools mentioned above. Their fields of application are continually widening owing to new carbides appearing, new production processes for manufacturing carbide articles of intricate shape and various sizes, and creation of high-production equipment and tools for working of carbides. In consequence of this technical progress carbide materials have recently been used for production of small solid cutting tools, for fitting woodworking tools, master forms for band-grinding machines, measuring instruments (micrometers, inside calipers, etc.), rollers for wire spreading, parts of devices and machines that are subjected to frictional wear, various nozzles and components working under abrasive wear conditions or in chemically corrosive atmospheres, etc.

CHAPTER X

Machining of Sintered Carbides

10.1. Classification of Machining Methods

After sintering, the surface of hard alloys is rough and sometimes warped and requires some kind of surface finishing.

The methods used today for finishing carbide surfaces may be divided into three groups:

1. Those based on chemical effects on the cobalt component of the carbide.
2. Those based on a combination of mechanical, chemical, and electrical effects on the carbide.
3. Those making use of abrasive or diamond tools.

The first group of methods is of no practical importance, but the second and, especially, third group are extensively used in industry.

The second group includes the following methods:

(a) anode-mechanical and electrolytic machining;
(b) electrolytically-assisted grinding;
(c) discharge machining; and
(d) ultrasonic machining.

The third group includes abrasive and diamond machining.

Abrasive machining includes grinding with silicon-carbide wheels and subsequent finishing by silicon-carbide wheels and sticks and lapping by cast-iron laps with boron-carbide paste. Diamond machining includes grinding and finishing by diamond wheels and sticks and lapping by iron-cast laps with diamond paste.

The anode-mechanical and electrolytic machining has a limited application. They are used chiefly in processing the supporting flats of carbide tips for cutters and sometimes in flat and profile grinding.

A wider use of these methods is hampered by an insufficient knowledge of the processes and by the negative effect of erosion of the cobalt component on the carbide strength.

The anode-mechanical method, used for rough machining of carbide parts, has a limited use which is further restrained by the disadvantages inherent in this method, such as the use of water glass as the working liquid and a rather low efficiency in finishing operations.

The electrolytic machining is an advanced variety of the anode-mechanical method. The combined electrochemical and mechanical effect of the tool upon the carbide increases the production rate and improves the finish of the machined surface. This method has good prospects for future development; it is acquiring ever wider applications in surface and internal cylindrical grinding, as well as in honing and sharpening of carbides.

The method of electrolytically-assisted grinding is used as a finishing process for carbide parts. This method yields a surface finish of class 10 to 11 (mirror gloss). It is used in the manufacture of drawing dies and plates.

The extensively used electric discharge method permits the manufacture of carbide parts of complex shapes, as well as roughing and, in many cases, finishing operations on sintered carbides.

The larger is the machining allowance, the more efficient can the electric-discharge method be used.

The method of ultrasonic machining has a limited use. It is used in some cases for the manufacture of blanking dies and punches, drawing dies and press moulds. This method yields a high surface finish and a high accuracy of holes and hollows in carbide parts. A wider use of ultrasonic machining is hindered by its low efficiency, long duration of the machining cycle, impossibility of obtaining large surfaces and deep holes, difficulty of making the tools. The surface finish is close to that obtained in electric-discharge machining.

Grinding of carbide products with wheels of green silicon carbide is extensively used in the fabrication of various tools, dies, carbide tips, etc. This method is used for grinding of carbide tools. In the finishing operations, this method does not provide the required efficiency, quality, and accuracy. Finishing of carbide tools and parts is carried out with sticks of green silicon carbide, cast-iron laps and blocks with boron-carbide paste.

Grinding with diamond wheels and sticks and lapping with cast-iron laps and diamond paste have lately found extensive application, especially in grinding of cutting tools and carbide parts, such as single-point cutters, counterbores, reamers, parts of blanking, upsetting, and drawing dies, rolls, broaches, milling cutters, etc.

Superfinishing with diamond and cast-iron laps and diamond pastes is used for profiled articles and parts, when the use of diamond wheels becomes impossible because of the complex shape of the part. The diamond lapping ensures a high accuracy and a surface finish of class 9 or higher.

10.2. Chemically- and Electrolytically-Assisted Machining

The essence of the chemically-assisted method of machining is as follows. When a carbide article is immersed into an electrolyte, cobalt forms galvanic microcells with the metal of the salt dissolved in the electrolyte. Usually, an aqueous solution of copper sulphate $CuSO_4$ is used for this purpose.

A reaction of substitution takes place between cobalt of the sintered carbide and copper of the electrolyte: cobalt passes into the solution, and copper settles on the surface of the article and forms a protective film. These electrochemical phenomena soften the surface layer of the carbide article and, when subjected to mechanical action of the wheel, the copper film and the loosened layer of carbide are easily removed, and the process of destruction of carbide binder begins over again.

The essence of electrochemically-assisted machining is that the carbide is destroyed as a result of a chemical reaction with the electrolyte and mechanical removal of the destruction products (like in chemically-assisted machining), but application of electric current intensifies the process and increases its rate three to four times.

In this method of treatment, direct current is used, the carbide article serving as the anode and the sharpened tool as the cathode.

The carbide article is fixed in special devices and fastened to it or bonded by means of a mixture of sulphur, wax, and rosin.

Electrochemically-assisted machining does not create thermal stresses, thus eliminating the possibility of crack formation and discoloration, and provides a good surface finish. The accuracy of grinding, i.e., the non-parallelism of the sides of carbide tips would range from 0.05 to 0.03 mm.

Variants of this method are the anode-mechanical and electrolytically-assisted machining.

ANODE-MECHANICAL MACHINING

This method is essentially as follows: working fluid *3* (Fig. 10.1) is delivered between workpiece *1* and tool *4*. The workpiece serves as the anode and the tool as the cathode. Electric current causes film *2* to be formed on the

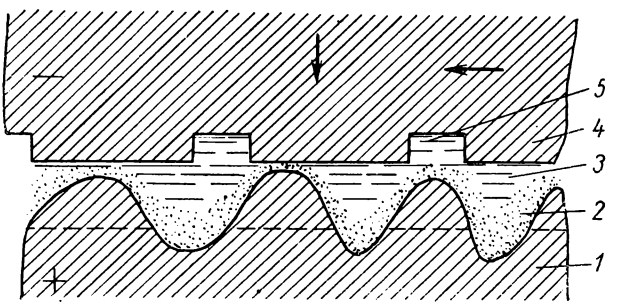


Fig. 10.1. Metal removal in anode-mechanical machining
1 — workpiece; *2* — film; *3* — working fluid; *4* — tool; *5* — groove channels

carbide surface of the workpiece, this film being removed by the roration of disc *4* and withdrawn through groove channels *5*.

When machining sintered carbides, a voltage of 18 to 20 volts is applied, and the disc is rotated at a peripheral speed of 15 m/s. The disc made of copper is immersed into an aqueous solution of a silicate (sodium or potassium silicate or clay suspension). Water-glass composition with a density of 1.43 to 1.55 is generally used.

The anode-mechanical method has a limited application because the liquids used tend to solidify.

ELECTROLYTICALLY-ASSISTED MACHINING

The essence of this method of carbide processing is in the joint effect of a diamond or abrasive tool and electrochemical action of direct current passing through the workpiece and the tool. The workpiece is connected to the positive line, and the tool to the negative line of the current source. The method of electrolytically-assisted grinding is diagrammed in Fig. 10.2.

Steel is machined with current-conducting wheels of silicon carbide or synthetic aluminium oxide, while carbides

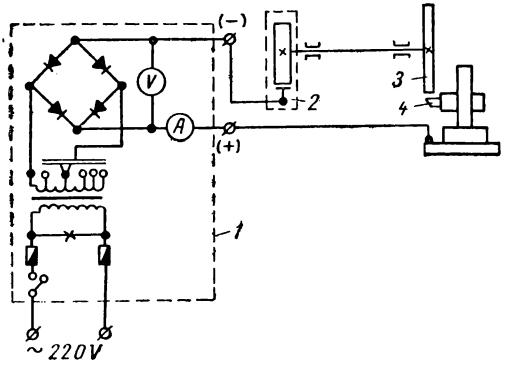


Fig. 10.2. Electrolytically-assisted grinding
1 — rectifier; *2* — collector; *3* — diamond wheel; *4* — workpiece

require diamond wheels with metal or bakelite binders and graphite filler. The electrolyte is a solution (10-15 per cent) of KNO_2 or KNO_3 with the addition of 0.5 per cent sodium nitride, an anticorrosive additive. The wheel peripheral speed V_{wh} is 30 to 40 m/s, the wheel pressure on the workpiece surface is 5.0-3.0 kgf/cm^2, the traverse speed is 1.0-1.5 m/min, the voltage is 8 to 10 volts, and the current density is 20-40 A/cm^2. Electrolytically-assisted machining makes use of standard grinding and tool-grinding machines which, however, require certain modifications: the machine spindle is fitted with a current-collector ring and copper-graphite brushes to which the negative pole of the current source is connected, while the positive pole is joined to the machine table. A tank with the working

fluid, electrical equipment (a control panel, measuring instruments, and protective devices), and a generator or rectifier are also included in the installation. The industry makes special machines for electrolytically-assisted grinding.

The method is especially effective when carbides are machined with diamond wheels and sticks. The rate of machining is then increased with no defective layers appearing and the surface finish of class 9 or 10 can be attained.

GRINDING WITH CONDUCTIVE ABRASIVE WHEELS

Conductive abrasive wheels are used for grinding carbide parts when high accuracy and surface finish are required. The method yields mirror-like surfaces of sintered carbides, finished to class 10 or 11.

The method is essentially as follows: carbide articles are machined with lead-impregnated or graphitized abrasive

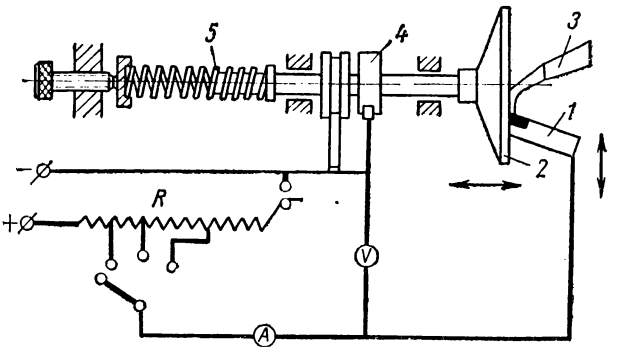


Fig. 10.3. Electroabrasive grinding
1 — workpiece; *2* — tool; *3* — fluid supply; *4* — current collector; *5* — shock absorber

wheels. To intensify grinding, a direct current and a working fluid are fed to the abrasive wheel and the workpiece (Fig. 10.3). The wheel functions simultaneously as the cathode and as the tool that removes the products of carbide destruction.

Direct current is supplied from a d.c. generator. The working fluid is either water glass, or 10 per cent aqueous solution of sodium chloride, or 1-1.5 per cent solution of

borax. The working fluid is periodically applied with a brush to the abrasive wheel surface.

Vitrified abrasive wheels of synthetic aluminium oxide impregnated with lead, medium-soft (CM2 hardness) and

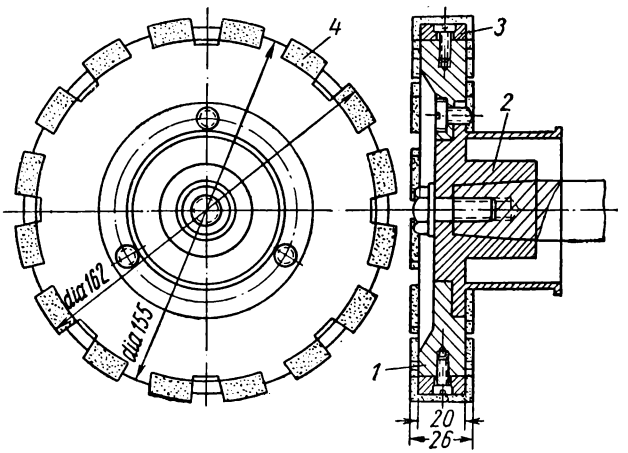


Fig. 10.4. Electroabrasive wheel assembly
1 — wheel core; *2* — flange; *3* — clamp plate; *4* — abrasive plate

with grain size 32-16 are recommended for electroabrasive machining. Dies are better ground with graphitized abrasive wheels.

The electroabrasive wheel is diagrammed in Fig. 10.4. The circumference of this wheel carries abrasive plates with gaps allowed between them.

Table 10.1

Electroabrasive Machining of Carbides

Process	Voltage	Ballast resistance, ohms	Current, amperes	Machining time, minutes
Roughing	30-32 max.	—	30-50	Till smooth surface is obtained
Grinding	26-28	0.25-0.5	10-15	2-3
Finishing	10-12	1.5-2.0	3-5	1 min (to mirror gloss)

Good quality of machining is obtained with wheel speeds of 15 to 30 m/s. The best conditions of carbide machining at such speeds are given in Table 10.1.

10.3. Discharge Machining

Discharge machining is used to cut and grind sintered carbides to a high accuracy and surface finish.

The method used is as follows. When a current pulse passes between electrode *1* and workpiece *2*, the heat produced by the current causes the workpiece material to melt and evaporate. The arrangement of zones subjected to the thermal effect is given in Fig. 10.5. The dimensions of the

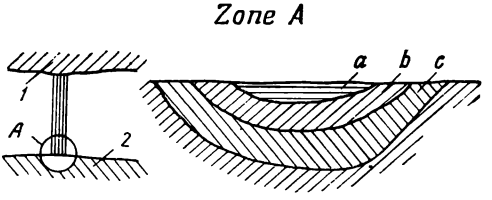


Fig. 10.5. Zones of thermal effect of current pulse
a — evaporated volume; *b* — melted volume; *c* — heated-affected volume; *1* — electrode; *2* — workpiece

zones depend on the intensity and duration of the current pulse. The heating destroys the cobalt component of the sintered carbide and causes microcracks in the surface layer. Hence, machining actually consists in the thermal effect of spark discharges between the electrode and the workpiece; the temperature of the discharges reaches tens of thousands of degrees.

The applications of and the quality obtained from the electric discharge method are given in Table 10.2.

The applications of this method are classified by production characteristics as:

(a) machining with forward motion of the tool and a fixed workpiece (similar to planing, slotting, and drawing);

(b) machining with the tool moving and the workpiece rotating (similar to turning) or with the tool-electrode rota-

Table 10.2

Applications of and Quality Obtained by Various Methods of Discharge Machining of Sintered Carbides

Method of machining	Applications	Quality obtained		Tool		Production data
		accuracy, mm	class of surface finish	material	manufacturing method	
Direct duplication	Female blanking dies	0.01	10	Copper, brass, cast iron, coke-graphite	Conventional and discharge machining	—
	Male and female embossing dies	0.01	9	Copper	Die embossing	12 hours required to manufacture carbide parts of die *vs* 40 hours for steel dies
	Threads; female dies with shaped helical surface	to class 2 or 3	8	Copper, brass, cast iron	Conventional machining	M8 thread in 15-mm plate made in 20 minutes
	Orifices, draw holes, drawing dies of various shapes and sizes	0.005	10	Copper, brass, cast iron, coke-graphite	Conventional and discharge machining	—
	Tools of complex profiles	0.001–0.02	8	Coke-graphite	Conventional machining	Several cutters of complex profile are made in 1 hour
Reverse duplication	Male dies	to class 2	9	Copper, brass, cast iron	Conventional and discharge machining	—

Cutting with electrode wire	Simultaneous manufacture of male and female dies for blanking metal sheet thicker than 1 mm	±0.005	9	Wire of tungsten, molybdenum, brass or copper	Conventional and discharge machining	32 hours required for carbide dies *vs* 50-60 hours for steel dies
	Simultaneous manufacture of male and female dies for some types of bending operations	±0.005				6 hours required for carbide dies *vs* 20 hours for steel dies
	Separate manufacture of male and female dies	0.01				—
	Tools, gauges, and templates of complex shapes	0.01				1.5-3 hours required for manufacturing some carbide parts *vs* 3-15 hours for steel parts
	Tools for die manufacturing by direct and reverse duplication	0.003-0.005				—
Grinding	Surface	0.01	8	Cast iron, coke-graphite	Conventional machining	—
	Cylindrical	0.01	8	Coke-graphite, cast iron		—

Continued

Method of machining	Applications	Quality obtained: accuracy, mm	Quality obtained: class of surface finish	Tool: material	Tool: manufacturing method	Production data
Grinding	Internal	0.01	8	Coke-graphite, cast iron	Conventional machining	Removal of 5-mm allowance by discharge machining is 5 to 10 times faster than by abrasive grinding
	Profile	0.01	8	Coke-graphite, cast iron, copper, brass	Conventional machining	Thread-cutting and other types of tools can be made
Combined methods	Direct and reverse duplication. Manufacturing of male and female dies without clearance	±0.003	10	Copper, cast iron, brass, coke-graphite	Conventional and discharge machining	Sets of male and female dies of any comple-xity and with any clearance can be made
	Cutting with electrode-wire and reverse duplication. Manufacturing of male and female dies for parts of any thickness	±0.005	9	Wire of tungsten, molybdenum, brass, or copper	—	Male dies of most complex shapes, precisely matching their female counterparts, can be made

ting and the workpiece moving (similar to milling, counterboring, surface grinding, and cutting);

(c) machining with both the tools and the workpiece rotating (similar to cylindrical grinding).

PROCEDURE FOR DISCHARGE MACHINING

Machining of carbides makes use of direct current. Pulse generators are used for this purpose. The principle of operation of the unit is as follows. The capacitor is charged from a d.c. source through a ballast resistor. The workpiece is connected to the positive terminal of the circuit (anode)

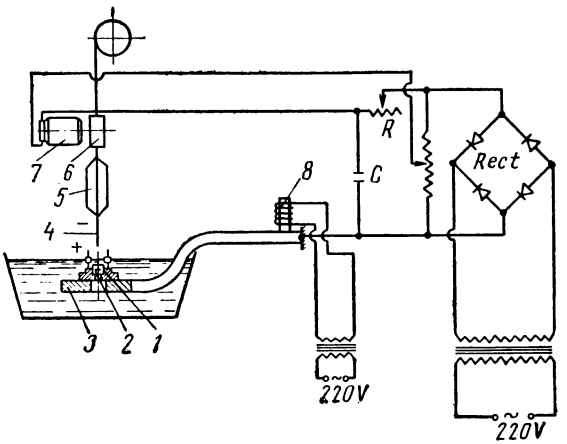


Fig. 10.6. Discharge-machining unit

1 — workpiece; *2* — replaceable washer; *3* — table; *4* — tool wire; *5* — jig; *6* — rollers; *7* — direct-action regulator; *8* — vibrator

and the tool, to the negative terminal (cathode). As the electrodes are brought closer together, a breakdown occurs in the electrode gap, and the electric power accumulated by the capacitor is discharged in a pulse of short duration. The pulse destroys particles of the carbide surface.

Diagram of the discharge-machining unit for making small-diameter holes is shown in Fig. 10.6. Carbide workpiece *1* is mounted in the seat of replaceable brass washer *2* which is fixed on table *3* of the unit; the axis of the seat

coincides with the axis of tool wire *4*. The wire, directed by jig *5*, is moved by rollers *6* which are driven by direct-action regulator *7*.

To ensure the removal of products of carbide destruction, the table with the workpiece is subjected to vibration at a frequency of 50 or 100 IIz produced by electromagnetic vibrator *8*. The amplitude of the table vibration is 0.01-0.05 mm. Capacitor *C* is charged from a rectifier through resistor *R*.

The tool and the carbide workpiece are immersed into a dielectric liquid (kerosene or transformer oil). In the course of machining, the liquid between the electrodes should be in motion, for which purpose it is pumped through by pressing, sucking, or jet pumps.

The intensity of tool wear influences all the technical and economic factors in discharge machining. The intensity of tool wear, in turn, depends on the tool material. Practice shows that maximum efficiency is attained when using electrodes made of brass, tungsten, copper-graphite, tungsten-copper, molybdenum-copper, and coke-graphite compositions.

The highest economy is ensured by tools of brass, copper, cast iron, and coke-graphite. Steel, aluminium, and graphite are absolutely impracticable as tool materials for machining carbides. Tools are made in the form of wire, wheels, or shaped parts.

METHODS OF DISCHARGE MACHINING OF CARBIDE PARTS

The following methods of discharge machining of carbides are employed:

1. Direct duplication of the geometrical forms of the tool in the workpiece.
2. Cutting of a part by a non-shaped tool (a continuously moving wire).
3. Grinding of carbide products.
4. Combined methods.

The method of direct duplication is the most popular in discharge machining of carbides. The principle of this method is that the tool introduced into the workpiece is identical in geometry to the required shape. As an example,

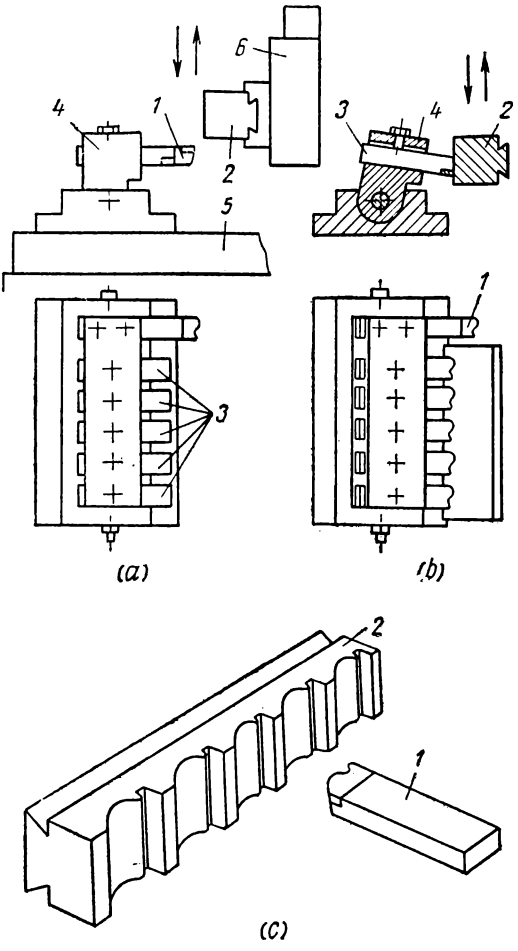


Fig. 10.7. Making a profiled cutter by direct duplication
1 — profiling cutter; *2* — electrode; *3* — cutter blanks; *4* — cutter holder; *5* — machine table; *6* — working head

we shall consider the manufacture of a profiled cutter by this method.

A profiled cutter is made in a generator-supplied discharge-machining unit as follows (Fig. 10.7). A preformed blank

of electrode *2*, made of coke-graphite material, is mounted in working head *6* of the machine. Profiling cutter *1* for truing the electrode and cutter blanks *3* are installed in special cutter holder *4* fixed on table *5* (Fig. 10.7*a*). Working head *6* is reciprocated, and profiling cutter *1* forms the profile on the electrode (Fig. 10.7*c*). After the electrode has been shaped, roughing discharge machining of cutters *3* begins. On removal of the bulk of metal from the cutter shank and of the carbide from the tip, table *5* with cutters *3* is brought closer to electrode *2*, leaving the normal clearance between them, and final machining is carried out. When the profile has been formed by the discharge method, cutters *3* are brought in contact with electrode *2* and working head *6* is given a reciprocating motion (Fig. 10.7*b*) for cleaning and finishing the profiles of cutters *3*. Fifteen to twenty cutters may be machined simultaneously in the machine.

By the direct-duplication method the following operations may be carried out: cutting of round and flat blanks, cutting of shaped blanks, making holes in a part, formation of female threads in parts, making female halves of embossing dies, cavities of forging dies, punches for bolt head upsetting, drawholes and draw dies for drawing rods with circular and shaped sections, working cavities of punches for upsetting various parts, and chipbreakers.

Cutting with a non-shaped electrode. The methods of direct and reverse duplication require the making of complex-shaped electrodes. In some cases it is a better practice to cut out a part with a non-shaped electrode, e.g., with a wire electrode.

The method used is as follows. A ground blank with a template fixed to it is mounted on the machine table. The machine has devices for moving wire electrode *1* in respect to the blank (Fig. 10.8). The wire is wound from coil *2* onto coil *3*, passing through a guiding system which consists of rollers *4* and a guide clamp. In the course of machining the part travels relative to the continuously moving wire. The blank with the template is between the guiding elements of the clamp; the direction of the blank travel is determined by the dimensions and shape of the template fixed to the blank, but isolated from it. The wire is simultaneously the electrode and the feeler which controls the motion of the

blank relative to the wire. The template is secured to the blank by means of bolts, clamps, or adhesives. Brass is used as the wire material.

The tools made by the wire-electrode method may be divided into two groups according to the production techniques:

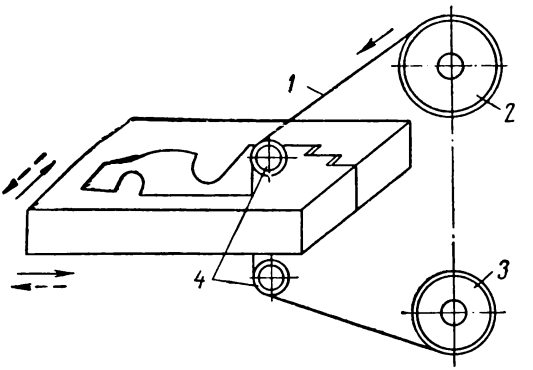


Fig. 10.8. Machining with a continuously moving wire
1 — wire electrode; *2*, *3* — coils; *4* — rollers

(a) tools with no parts mating along the contour (upsetting dies, punches, draw dies, templates, gauges);

(b) tools with mating parts (male and female parts of blanking dies).

When making parts of the first group, the wire is cut right through the blank and the further relative movement is carried out automatically, following the template. When making parts with an internal contour, the wire is introduced through a hole drilled inside the contour.

This method is best for manufacturing parts with a curvilinear contour. It is used for curvilinear cutting of parts, manufacturing of male and female halves of bending and cutoff dies, profiled single-point cutters, thread chasers, and chipbreakers.

GRINDING OF CARBIDE PARTS

Spark grinding of carbides is finding ever wider use.

A rotating electrode in the form of a wheel of cast iron, coke-graphite or copper grinds the surface of the carbide

part. The circumference of the wheel has a contour reverse to that of the workpiece. The electrode wheel is trued with a coke-graphite profiling wheel.

Spark grinding includes the following operations: wheel grinding of internal and external cylindrical and conical surfaces, grinding of flat surfaces and removal of large allowances from cylindrical and flat surfaces by means of a continuously moving wire.

High-quality machining of carbides is best obtained at speeds of 15 to 20 m/s.

Spark grinding of carbides is carried out in a bath filled with transformer oil. Machine pulse generators supply the current. Machining of carbides is carried out at three ratings of current with short-circuit currents of 28, 17, and 9 amperes.

Spark grinding of flat and cylindrical surfaces is used to advantage in rough machining of carbide parts and in removal of large allowances. To obtain a surface finish above class 7 or 8, a finishing operation of diamond grinding or lapping with boron-carbide paste is necessary. In this case, the diamond grinding must use 0.10 to 0.12 mm grains and lapping with boron carbide requires grains not over 0.05 mm.

Spark grinding is very efficient in making parts of a complex shape, such as profile cutters.

10.4. Ultrasonic Machining

Ultrasonic machining of carbides is carried out with loose abrasive grains energized from a source of vibrations.

This method is as follows: tool *2* (Fig. 10.9) is joined to magnetostrictive transducer *5* with the help of tool holder *8*. The magnetostrictive transducer consists of a set of blades made of pure nickel, free at the top and welded to the transmitting cone at the bottom. The length of the nickel blades changes under the effect of magnetic forces created by exciting coil *6*, and the mechanical oscillations thus created are transmitted through cone *7* to tool tip *2* whose contour is a mirror reflection of the contour of machined surface *1*. Abrasive slurry *3* is delivered to the machining zone. Passage of electric current liberates large

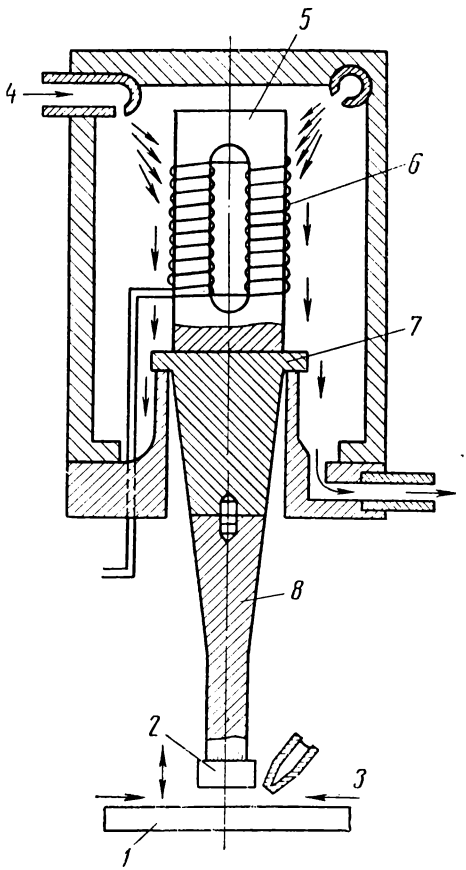


Fig. 10.9. Magnetostrictive transducer

1 — machined surface; *2* — tool tip; *3* — abrasive slurry; *4* — coolant supply; *5* — transducer; *6* — exciting coil; *7* — cone; *8* — tool holder

amounts of heat, therefore coolant *4* is applied. A slurry of abrasive powder in water or oil is fed into the machining zone. The grains strike the surface of the carbide (with a force tens of thousands of times their own weight) and destroy it, each grain repeatedly striking the surface 20 to 30 thousand times per second.

The tool is made of cold-drawn or mild non-hardened carbon steel, brass, tungsten carbide, etc. Synthetic aluminium oxide, silicon carbide, and boron carbide are used as abrasives. The granularity of the abrasive is chosen to suit required surface finish, using fine grain for a high finish and coarse grain for roughing. The abrasive concentration is 30 to 50 per cent. The vibration amplitude of the abrasive particles ranges from 25 to 130 μ.

Table 10.3 gives data concerning the influence of the abrasive grain size on the surface finish and the accuracy of manufacture. Data for the influence of the tool material on the efficiency are presented in Table 10.4.

Ultrasonic machining requires special machines.

Table 10.3

Quality of Ultrasonic Machining of Carbides

Factor	Surface machined	Boron carbide grain size			
		10	5	3	M14
Class of surface finish	Conical, cylindrical, and blind holes	5-6	6-7	8	9-10
Accuracy of machining, mm	Conical holes	± 0.02 -0.04	± 0.02	± 0.01	± 0.005
	Cylindrical and blind holes	$+0.05$ -0.01	$+0.03$ -0.01	$+0.02$	$+0.01$

Table 10.4

Tool Material *vs* Cutting Speed

Tool material	Boron carbide grain size	Cutting speed, mm/min, at vibration amplitude	
		50μ	25μ
Copper	12	1.6	0.41
	3	0.51	0.015
Brass	12	2.3	0.56
	3	0.71	0.020
Mild steel	12	2.2	0.53
	3	0.56	0.018
Silver steel	12	1.9	0.51
	3	0.56	0.020
Stainless steel	12	1.8	0.46
	3	0.51	0.015
Sintered carbide	12	3.9	0.96
	3	2.54	0.76

10.5. Abrasive and Diamond Grinding

Abrasive and diamond grinding is extensively used for machining of carbides.

Abrasive machining includes:

(a) grinding with silicon-carbide wheels;

(b) finishing with silicon-carbide wheels and sticks; and

(c) lapping with cast-iron laps and a paste of boron carbide.

Diamond machining includes:

(a) rough and finish grinding with diamond wheels and sticks;

(b) lapping with cast-iron laps and diamond paste.

Diamonds are very hard, 2.5 to 3.0 times harder than silicon carbide and 6 times harder than sintered carbides. The application of diamonds permits an improvement in quality of carbide machining and an increase in the production rate. The life of single-point tools increases 1.5-2.0 times as compared with machining by wheels of silicon carbide or synthetic aluminium oxide; the life of multi-point tools increases 2-3 times, that of parts of dies and drawholes, 10 times; the surface finish grows to class 7 to 11 in grinding, class 9 to 13 when lapping with wheels, and class 10 to 14 when lapping with loose grains; labour consumption and net costs are reduced twice in grinding and ten times in lapping; the working conditions are also improved.

PROCESS OF ABRASIVE AND DIAMOND GRINDING

Grinding is a metal-cutting process that employs an abrasive wheel whose cutting elements are grains of abrasive materials. The actual cutting process in grinding is the result of the action of sharp edges of the abrasive grains that cut (abrade) a layer of metal in the form of very minute chips. A grinding wheel can be self-sharpening in the course of the grinding process, i.e., the action of the additional load on a dulled grain may split it or, what is more frequent, may tear it out of the bond so that new, sharp cutting edges are presented to the work. Self-sharpening would be a result of proper wheel choice, the cutting characteristics of the grinding wheel being restored in the process of machining.

This is an advantage of the grinding wheel as compared with other cutting tools.

Grinding wheels can remove very thin layers of material, therefore grinding is used for obtaining final dimensions

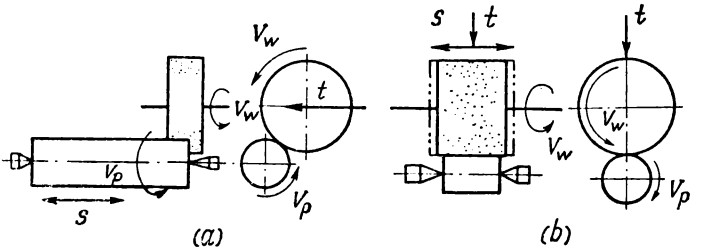


Fig. 10.10. Grinding layouts
(*a*) traverse grinding; (*b*) plunge-cut grinding; V_p — circular feed; V_w — peripheral speed of the wheel; S — traverse; t — infeed

and a high surface finish on the machined parts, i.e., as a finishing operation.

Grinding permits machining of extremely hard materials, including carbides.

The surfaces made by grinding may be simple (external and internal cylindrical surfaces, plane) or shaped (conical, helical, involute).

Grinding requires that the workpiece and the grinding wheel have corresponding relative motions. The modes of grinding are classified as cylindrical, internal, and surface grinding.

Cylindrical grinding. Four methods of cylindrical grinding are known: traverse grinding; plunge-cut grinding; through-feed centreless grinding; and infeed centreless grinding.

In traverse grinding (Fig. 10.10*a*), the wheel performs two movements: rotation about its axis (main cutting motion) and infeed into the work to remove the grinding allowance (usually an intermittent crosswise motion at the ends of the traverse strokes). The work rotates about its axis (circular feed) and is traversed lengthwise past the wheel so as to extend the grinding action over the full length of the work. The crosswise motion of the wheel, i.e., infeed

to a definite depth, is accomplished when the workpiece has completed a full stroke (back and forth). In some cylindrical grinders, the workpiece only rotates and the wheel is imparted three motions (rotation, infeed, and traverse).

In plunge-cut grinding (Fig. 10.10*b*), there is no traverse motion of either the wheel or the work. The grinding wheel extends over the entire length of the surface being ground on the workpiece which rotates about its axis. The wheel rotates and at the same time is continuously fed into the work. In plunge-cut grinding the following motions are required: rotation of the grinding wheel, rotation of the workpiece (or circular feed), and continuous crossfeed of the wheel.

Centreless grinding is a variant of cylindrical grinding. The workpiece is placed on the work rest blade between the grinding wheel and regulating wheel. In through-feed centreless grinding, it is necessary to ensure the following motions: rotation of the grinding and regulating wheels, circular feed motion of the work, and traverse. The rotation and traverse motion is imparted to the workpiece by the regulating wheel installed at a small angle to the axis of the grinding wheel.

Internal grinding. In internal grinding, used for machining a hole in the work, the grinding wheel moves inside the hole. This type of machining includes traverse grinding, plunge-cut grinding, through-feed centreless grinding, and infeed centreless grinding. In internal grinding, the motions are the same as in cylindrical grinding.

In centreless internal grinding, like in cylindrical grinding, the workpiece is not secured; in the process of grinding it is supported by a pair of support rolls.

Surface grinding may be performed either with the periphery or with the face of a wheel.

In surface grinding the following motions are used: rotation of the grinding wheel (main cutting motion), traverse of the workpiece, rectilinear motion of the work or wheel across the direction of traverse, and crosswise motion of the wheel into the work (infeed).

Grinding machines. In accordance with the shape of the surface to be ground, grinding machines are classified as

cylindrical grinders, internal grinders, surface grinders, and profile grinders. The internal grinders may be further divided into chucking, planetary, and centreless types.

In addition to the general requirements to tool grinding by abrasive wheels, diamond wheels pose more exacting requirements to the machine: the machines must be of rather high, high, very-high, and ultra-high precision. For cylindrical grinding machines of rather high and high precision are employed. For surface and profile grinding, very-high-precision machines are used.

Machines for diamond grinding must satisfy the following additional requirements:

(1) high rigidity and vibration resistance; the rigidity should be 500 to 900 kg/mm. The amplitude of vibrations of the machine-workpiece system should be in the range of 5 to 10 μ;

(2) provision of a system of cooling with a pad, liquid jet, or atomized liquid;

(3) careful balancing of the rotating elements of the machine; radial and axial play of the spindle should not exceed 0.01 mm, but 0.005-mm limit is preferable;

(4) provision of wheel rotation at peripheral speeds of 15 to 45 m/s and 3 or 4 ranges of spindle speeds;

(5) infeed and traverse control with an accuracy of 0.005 mm;

(6) power-driven traverse and infeed motions.

Grinding fixtures. Standard and special fixtures are used for mounting carbide articles in the machines.

When grinding sides of carbide tips, they are placed on a magnetic chuck and backed by bars to prevent them from shifting in grinding. The bar should be 1 to 2 mm thinner than the tips to be ground.

Other fixtures are also used. One example is a steel plate with a T-slot which houses sliding blocks with cams of various shapes to suit the shape of the carbide tips. A nut and bolt passing through the hole in the slide blocks, tighten the blocks and clamp the carbide tips in the fixture. The fixture with the tips is installed on the magnetic chuck of the machine and held there by magnetic forces.

The tips of the same thickness are selected for simultaneous grinding. When grinding the sides of a tip, the latter

is placed with its convexity upward. Grinding proceeds until 80 to 90 per cent of tips are completely ground, the remaining tips being ground with the next batch.

When machining the bearing face of the tip, it is clamped in a vise fixed to the magnetic chuck of the machine. Sometimes a fixture is used that secures several carbide tips at a time.

FEEDS AND SPEEDS IN GRINDING

The peripheral speed V_w of the wheel in metres per second can be calculated by the formula

$$V_w = \frac{\pi D_w n_w}{60 \cdot 1000}$$

where D_w = diameter of the grinding wheel, mm
n_w = speed of the grinding wheel, r.p.m.

The peripheral speed of the workpiece is usually called the circular feed. Its value in metres per minute can be calculated by the formula

$$V_p = \frac{\pi D_p n_p}{1000}$$

where D_p = diameter of workpiece, mm
n_p = speed of the workpiece, r.p.m.

The cross movement of the wheel in the direction of the workpiece is called the depth of cut or infeed, t, and measured in millimetres per double table stroke or millimetres per minute.

The rate of traverse, S, is the distance along the wheel axis, travelled by the wheel (or workpiece) during one revolution or one stroke of the workpiece. Usually, the rate of traverse is specified in terms of wheel width per workpiece revolution or in metres per minute.

The power required for wheel rotation in grinding is calculated by the formula

$$N_w = \frac{P_z V_w}{102h}$$

where N_w = power required for grinding, kW
P_z = cutting force, kgf

V_w = peripheral speed of the wheel, m/s
h = efficiency of machine drive (0.8 to 0.85)

Knowledge of the cutting force P is necessary for rating the electric motor to drive the machine. The surface finish

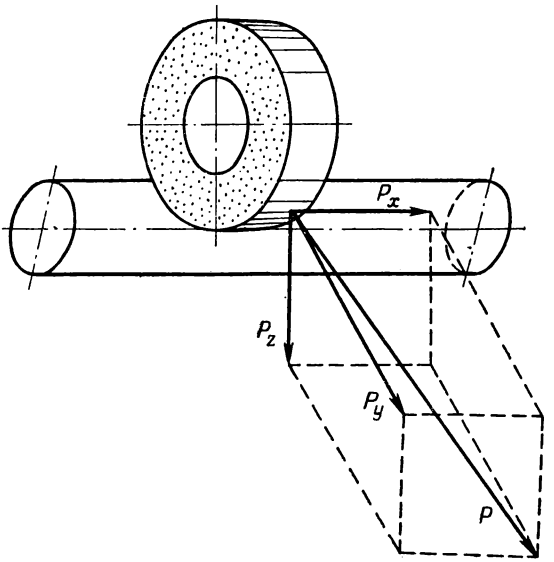


Fig. 10.11. Cutting forces in grinding

and machining accuracy obtained are also dependent on this force.

The resultant cutting force P can be resolved into three components (Fig. 10.11):

(a) tangential force P_z
(b) radial, or feed, force P_y
(c) axial feed P_x

The tangential force is the actual cutting force calculated (in kilograms-force) by the formula

$$P_z = C_p V_p^{0.7} \cdot S^{0.7} \cdot t^{0.6}$$

where C_p = factor characterizing the material of the workpiece being ground.

The radial force P_y is one to three times more than P_z.

The rating, in kilowatts, of the electric motor required for grinding can be calculated by the formula

$$N_p = \frac{P_z V_p}{60 \cdot 102 h}$$

where V_p = peripheral speed of the workpiece, m/min
h = efficiency of machine drive (0.8 to 0.85)

FINISHING WITH ABRASIVE AND DIAMOND TOOLS

A high accuracy (to within 2 or 3 μ) and good surface finish (up to class 10 or 14) can be obtained by finishing operations.

Finishing can be accomplished by abrasive and diamond wheels and by loose grains. Lapping with fine-grained loose powders and pastes is most widely used.

Finishing with wheels uses the same principle as grinding, but with finer grain and lighter feeds and speeds.

Lapping with loose grains is a procedure in which the grains mixed with paste components remove the metal under the action of a lap, the working zone being cooled with a machining fluid.

Lapping of carbide articles is done by cast-iron blocks with pastes of boron carbide or diamond applied.

ABRASIVE AND DIAMOND MATERIALS AND TOOLS

Abrasive and diamond tools consist of granular materials held together by a bond. They differ in material, grain size, bond, hardness, and structure.

Abrasive and diamond materials are divided into natural and synthetic. The first group includes natural diamonds, corundum, garnet, quartz, and aluminium oxide (alumina). The second group includes synthetic diamonds, synthetic aluminium oxide, silicon carbide, and boron carbide.

Carbide articles are machined with natural and synthetic diamonds, boron carbide, silicon carbide, synthetic aluminium oxide, and cubical boron nitride (Table 10.5).

Natural diamond is a mineral consisting of only one chemical element, carbon. It is found as crystals weighing from 0.005 to several tens of carats (1 carat = 0.2 gram).

Table 10.5

Properties and Applications of Abrasive Materials

Abrasive material	Description	Main component	Hardness		Micro-hardness, kgf/mm²	Grinding capability	Temperature at which abrasive property is lost, °C	Tool forms and applications
			Mohs scale	Ridgeway scale				
Natural diamonds	Best grade, black	C	10	15	10,060	1.0	600–700	Wheels and sticks for machining of carbides and steels. Micropowders for lapping and polishing
Synthetic diamonds	Grey and colourless crystals	C	10	15	10,100	0.9	600	Sticks, laps, wheels, and powders for machining of carbides
Cubical boron nitride	Crystals, mostly dark-brown in colour	BN	10	15	8500–8600	1.0	1500–1600	Wheels and powders for machining hardened and difficult-to-machine steels and carbides

Continued

Abrasive material	Description	Main component	Hardness		Microhardness, kgf/mm²	Grinding capability	Temperature at which abrasive property is lost, °C	Tool forms and applications
			Mohs scale	Ridgeway scale				
Standard aluminium oxide	Crystals of aluminium oxide, brown-red or brown in colour	92–95% Al_2O_3	9	12	2000–2200	0.1–0.12	—	—
White aluminium oxide	Crystals of aluminium oxide, white or pink in colour	98–99% Al_2O_3	9	12	2300–2400	0.14–0.16	—	Wheels and micropowders for machining steels
Green silicon carbide	Green crystals	97–98% SiC	—	13	2900–3500	0.45–0.50	1000–1200	Wheels for grinding and sharpening. Grinding powders for lapping of carbides
Black silicon carbide	Black crystals	95–98% SiC	—	13		0.25–0.40		
Boron carbide	Black crystals	85–94% B_4C	—	14	3350–4300	0.5	—	Powders for lapping of carbides

Its density is 3.01 to 3.56. Diamond grains are extremely hard and wear-resistant, but their strength is not high, they are brittle. Therefore, they are used in tools designed for light loads in the absence of impacts and vibrations.

Synthetic diamonds are made of graphite by subjecting it to high temperatures and pressures. They have the same structure, physical and chemical properties as natural diamonds.

Synthetic aluminium oxide is an artificial abrasive material made by melting bauxite together with a deoxidizing agent (anthracite, coke) in an electric furnace. Depending on the Al_2O_3 content, the material is classed as standard (92 to 95% Al_2O_3) and white (98 to 99% Al_2O_3). Synthetic aluminium oxide features a high hardness and mechanical strength and is widely used in industry.

Silicon carbide is a chemical compound of carbon and silicon with a small amount of impurities (Fe_2O_3, SiO_2, etc.). It is obtained from a reaction of alumina with carbon, heated in an electric furnace. The two grades widely used are green silicon carbide and black silicon carbide. The former has a smaller content of impurities, therefore, its grinding capability is 20 per cent higher. Silicon carbide and synthetic aluminium oxide are widely employed for machining of carbides.

Boron carbide is a chemical compound of boron and carbon obtained by fusing boric acid with low-ash carbon material. Its abrasive capability and hardness are higher than in any other abrasives with the exception of diamonds. Boron carbide is mainly used as pastes and powders for finishing carbide articles.

Cubical boron nitride as an abrasive is not inferior to diamonds, but has a much higher heat resistance (up to 1500-1600°C). When manufactured artificially it is obtained in the form of monocrystals with sizes of 300 to 600μ. This new abrasive will, probably, find extensive application.

The grain size of an abrasive material characterizes the linear dimensions of its grains. Abrasive materials are screened for classification into different sizes. The granular composition of a material is determined by the content of fractions; the quantity and size of the main fraction is the principal characteristic of the material.

In the USSR, grain sizes are designated in terms of the mesh size (expressed in microns) of the screen on which the grain of the main fraction remains. For example, figure 40 designates an abrasive material with grains sized from 400 to 500μ. The grain sizes of abrasive materials are given in Table 10.6.

Table 10.6

Designation of Grain Sizes of Abrasive Materials

Grinding grains		Grinding powders		Micropowders	
grain size	limits of linear sizes of grains of main fraction, μ	grain size	limits of linear sizes of grains of main fraction, μ	grain size	limits of linear sizes of grains of main fraction, μ
200	2500-2000	12	160-125	M40	40-28
160	2000-1600	10	125-100	M28	28-20
125	1600-1250	8	100-80	M20	20-14
100	1250-1000	6	80-63	M14	14-10
80	1000-800	5	63-50	M10	10-7
63	800-630	4	50-40	M7	7-5
50	630-500	3	40-28	M5	5-3.5
40	500-400			M3	3-1
32	400-315			M1	below 1
25	315-250				
20	250-200				
16	200-160				

Bonds that integrate abrasive grains into a tool may be either inorganic (vitrified, silicate, oxychloride, etc.) or organic (resinoid, rubber, glyptal, etc.) materials. Vitrified, resinoid, and rubber bonds have found widest application.

The *vitified bond* consists of clay, feldspar, and quartz. The *silicate bond* includes water glass (sodium silicate) as the basic bonding material and fillers (zinc oxide, chalk, and plastic clay). The *oxychloride bond* is a mixture of caustic magnesite and magnesium chloride (magnesia cement).

The *resinoid bond* is made of liquid or powder bakelite which after heat-treatment becomes a strong and hard material. The *rubber bond* is rubber subjected to vulcanizing.

Glyptal bond is a synthetic resin made of glycerine and phthalic anhydride.

Hardness. The material of a cutting tool must be harder than that of the workpiece. The hardness of an abrasive material should be distinguished from the hardness of an abrasive tool. The hardness of an abrasive material may be determined either by the Mohs scale or by microhardness measurement. The Mohs hardness is determined by scratching one mineral with another. The Mohs scale has ten grades, the hardness of diamond being taken equal to 10 units and the hardness of talcum as one unit; other minerals are intermediate between these two.

The microhardness of an abrasive material is found by measuring the depth of the indentation left by the tip of a square-base diamond pyramid in the material under test. The microhardness of abrasive materials is given in Table 10.5.

The hardness grade of an abrasive tool characterizes the strength with which the bond holds the abrasive grains in the tool, opposing the external forces tending to pry them loose.

Table 10.7

Hardness Grades of Abrasive Wheels

Wheel grade	Grade designations	Materials to be ground by wheel
Soft (M)	M1, M2, M3	Sintered carbides, cast iron, nonferrous metals
Medium soft (CM)	CM1, CM2	Sintered carbides, cast iron, high-speed steel, nonferrous metals
Medium (C)	C1, C2	Structural and high-speed steels, bronzes
Medium hard (CT)	CT1, CT2, CT3	Structural steels of ordinary and high quality
Hard (T)	T1, T2	
Very hard (BT)	BT1, BT2	Wheel dressing and truing
Extremely hard (ЧТ)	ЧТ1, ЧТ2	

The grade of abrasive tools is determined by three principal methods:

(1) by sand-blasting (from the depth of the depression obtained when a definite volume of quartz sand is directed in a jet against the tool surface);

(2) by measuring the depth of indentation by a steel ball (Rockwell test); and

(3) by measuring the depth of indentation by a steel cone whose tip is made of BK6A carbide.

The grades of abrasive tools are given in Table 10.7.

The structure of an abrasive tool characterizes the ratio of volumes occupied by the grains, bond, and voids in the tool.

Structures of abrasive tools are designated by numbers, number 1 corresponding to 60 per cent of abrasive grains in unit volume. Data on structures of abrasive tools are given in Table 10.8.

Table 10·8

Structures of Abrasive Wheels

Structure number	Grain volume, %	Structure number	Grain volume, %	Structure number	Grain volume, %
Dense structures		*Medium-dense structures*		*Open structures*	
1	60	6	50	11	40
2	58	7	48	12	38
3	56	8	46	13	36
4	54	9	44	14	32
5	52	10	42	15	34
				16	30
				17	28
				18	26

ABRASIVE GRINDING WHEELS

Grinding wheels are available in standard shapes and sizes. The more widely used wheel shapes are shown in Fig. 10.12.

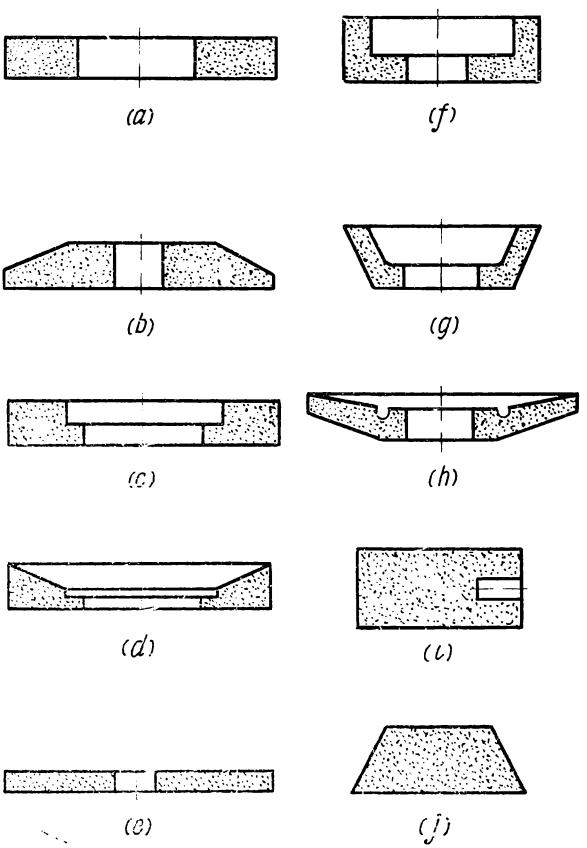


Fig. 10.12. Principal shapes of grinding wheels
(*a*) straight; (*b*) straight bevelled; (*c*) straight recessed; (*d*) straight relieved; (*e*) disc; (*f*) straight-cup; (*g*) flaring-cup; (*h*) dish; (*i*) cylindrical grinding point; (*j*) trapezoidal grinding segment

Straight wheels, simple in shape and versatile in application, are most popular. They are used for cylindrical, internal, and centreless grinding, for surface grinding, for thread, gear, and spline grinding, as well as for sharpening of various single- and multi-point carbide tools. Wheels

recessed one or both sides embed the wheel flanges, which allows the wheel to be advanced closer to the work.

Straight bevelled wheels are used mainly for grinding multi-point tools (e.g., milling cutters, gear teeth, etc.).

Disc wheels are used for cutting-off and slotting operations.

Straight-cup and flaring-cut wheels are used for surface grinding and tool sharpening.

Dish wheels are employed when the space near the surface to be machined is limited, for example, when grinding the faces of multi-tooth tools (milling cutters, slotters).

Tools of other shapes are also used sometimes, mostly in special-purpose grinders.

Grinding points are employed in making moulds and dies. Points are cemented onto a special stem which is secured to a chuck rotated by means of a flexible shaft. Points are also used for sharpening of round dies.

Segmental wheels are used in surface grinding. Such a wheel consists of several abrasive segments clamped in a chuck. Segmental wheel makes a coarser surface as compared to a cylindrical wheel, but can be used for more intensive cutting. Segments are also used for tool sharpening instead of straight-cup wheels.

ABRASIVE PASTES

Abrasive pastes are semiliquid or hard mixtures of abrasive materials with some other components. These pastes are used in lapping operations.

Pastes are classified according to their consistency as liquid, grease-like, and hard. In accordance with the abrasive material, pastes are divided into the following groups:

(a) hard materials (corundum, silicon carbide, boron carbide);

(b) soft materials (iron oxide, chromium oxide, aluminium oxide, talcum).

A specific feature of soft abrasive materials (chromium oxide and iron oxide) is that they affect the workpiece surface not only mechanically, but also chemically. Besides, other components of the pastes, such as oleic and stearic acids, also exert chemical effect on the workpieces and accelerate the working process.

Pastes have diverse compositions, each manufacturer makes them according to his own specifications and techniques.

According to the grain size, lapping pastes may be divided into three groups:

(a) coarse pastes with abrasive grain size of 20 to 100 μ, intended for rough lapping;

(b) medium pastes with abrasive grain size of 5 to 14 μ for semi-fine lapping;

(c) fine pastes with abrasive grain size of 1 to 3 μ for fine lapping of high-precision parts to a surface finish of class 11 to 14.

The abrasive for coarse and medium pastes is mainly synthetic aluminium oxide.

The abrasive content in coarse and medium pastes varies from 50 to 80 per cent and in fine pastes from 15 to 20 per cent. Usually, pastes contain 5 to 10 per cent diamond dust.

Lapping of precision articles is carried out in two to four consecutive operations with gradual increase in accuracy, changing the paste composition.

Sometimes, diamond and abrasive suspensions are used. Abrasive grains are here suspended in kerosene, oil or water.

DIAMOND WHEELS

Diamond wheels are used for grinding and sharpening carbides and steels. The design of a diamond wheel is shown in Fig. 10.13. The wheel has core *1* of duralumin or plastic and diamond section *2* containing diamond powder and a bond. Diamond wheels are specified in Table 10.9.

Diamond wheels are classified according to the bond, grain size, and diamond concentration.

Grain sizes of diamond powders are specified in Table 10.10. The grain size is selected to suit the machining allowance and desired accuracy of surface machining. Rough grinding is generally accomplished with A16 or A12 wheels, while finishing and polishing are done with AM28 to AM10 wheels.

Diamond wheels with metallic or bakelite bond are available. Metal-bonded diamond wheels are more wear-resistant, but they produce poorer surface finish and tend to be loaded. These wheels are used to remove large machi-

Table 19.9

Diamond Wheels and Their Applications

Wheel shape	Range of wheel diameters, mm	Type of bond*	Type of machine	Use	Note
Straight	12 to 320	M	Cylindrical grinder	Machining of solids of revolution	Grinding and finishing cylindrical surfaces
		O	Surface grinder	Machining flat surfaces	Grinding and finishing flat surfaces on dies, tools, etc.
Straight coreless	6 to 10	M	Tool grinder	Sharpening of tools	Grinding chip breakers on tools
	6 to 12	O	Internal grinder	Internal grinding	Grinding and finishing holes
Cylindrical points	3 to 16	M O	Jig grinder	Internal grinding	Machining curvilinear surfaces
Straight recessed one side	100 to 250	M O	Tool grinder	Sharpening of tools	Sharpening tools, machining parts of measuring instruments
Straight recessed two sides	100 to 250	M O	Tool grinder	Machining of tools	Sharpening and finishing tools, machining parts of callipers and gauges
Flaring-cup	50 to 200	M	Universal tool grinder	Machining of tools	Sharpening and finishing tools, machining parts of callipers and gauges
		O		Machining of flat surfaces	Grinding and finishing die parts
Dish	75 to 125	M O	Universal tool grinder	Machining of tools. Grinding of dies	Sharpening and finishing tooth faces of counterbores, milling cutters and other tools
Profile	50 to 125	M O	Profile grinder	Profile grinding	Sharpening profile tools, machining die parts

* M — metallic bond; O — organic bond.

ning allowances (up to 0.5 mm). The industry uses diverse metallic bonds, but the more common one contains 80% Cu and 20% Sn.

The wheels with organic bonds are used for grinding and finishing when small layers of metal (up to 0.1 mm) are to be removed. These wheels have a lower wear resistance as compared with metal-bonded, therefore, when large allowances are removed, their service life is ten times shorter.

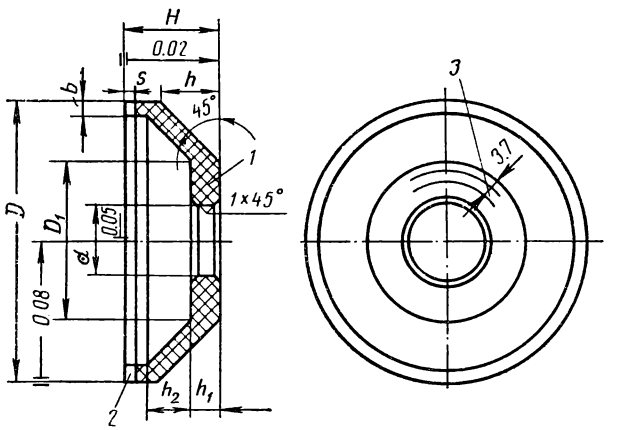


Fig. 10.13. Diamond cup wheel design

1 — core; *2* — diamond section; *3* — marking place; D — outer diameter of the wheel; d — hole diameter; s — diamond section thickness; b — diamond section width; h_1 — core base thickness; h_2 — cup height; D_1 — core base diameter; H — wheel height

The industry produces resinoid-bonded wheels with boron carbide or iron as fillers.

Resinoid-bonded diamond wheels make it practically possible to grind carbide tips together with the steel holder, but the wheel wear increases by 25-50 per cent.

Resinoid-bonded wheels can be used without cooling, whereas metal-bonded wheels must be cooled.

Surface finish as a function of the grain size of diamond powder and type of bond is presented in Table 10.11.

The concentration of diamond grains in wheels is the mass of grains in 1 mm^3 of diamond section, assuming the content of 0.878 milligrams of diamond per 1 mm^3 of diamond section as the 100 per cent concentration.

Table 10.10

Grain Sizes of Diamond Powders

Grade	Size of grains of main fraction, μ	Grade	Size of grains of main fraction, μ
A50	630-500	AM40	40-28
A40	500-400	AM28	28-20
A32	400-315	AM20	20-14
A25	315-250	AM14	14-10
A20	250-200	AM10	10-7
A16	200-160	AM7	7-5
A12	160-125	AM5	5-3
A10	125-100	AM3	3-1
A8	100-80	AM1	below 1
A6	80-63	—	—
A5	63-50	—	—
A4	50-40	—	—

Note. The grain size designations presented in the Table refer to natural diamonds. Powders of synthetic diamonds are designated similarly, but a letter "C" is added after "A", e.g., AC16, ACM40.

Table 10.11

Surface Finish *vs* Grain Size and Type of Bond of Diamond Wheel

Grain size	Class of surface finish	
	metallic bond	organic bond
A16-A10	7-8	8-9
A8-A6	8-9	8-10
A5-A4	—	9-10
AM40-AM28	—	10-11
AM20-AM10	—	11-13

Metal-bonded wheels always have 100 per cent concentration, but resinoid-bonded wheels are made with various concentrations, from 25 to 200 per cent. The concentration of diamond grains should be chosen in accordance with the nature of work and type of bond. When selecting a wheel, the data given in Table 10.12 may be helpful.

Table 10.12

Diamond Wheels for Various Grinding and Lapping Operations

Type of grinding	Machined material	Operation	Bond*	Grain size	Concentration, %
Surface (by wheel face)	Carbide	Grinding	M, V, P	16-10	100
		Lapping	D, R	6-M40	100-50
	Hardened steel	Grinding	V, R	12-8	100
		Lapping	R	6-4	150
Surface (by wheel periphery)	Carbide	Grinding	M, V	16-8	100
		Lapping	V, R	6-M40	100-50
	Hardened steel	Grinding	V, R	12-8	100-150
		Lapping	R	6-M40	100-150
Cylindrical	Carbide	Grinding	M, V	16-8	100
		Lapping	V, R	6-M40	100-50
	Hardened steel	Grinding	V, R	12-8	100-150
		Lapping	R	6-M40	100-150
Internal	Carbide	Grinding	M, V, P	12-8	100
		Lapping	D, V, R	6-M28	100-50
	Hardened steel	Grinding	V, P	12-8	100-50
		Lapping	R	6-4	100-150

* M — metallic, V — vitrified, R — resinoid, D — metallic finely dispersed, P — electroplated.

Diamond grinding points. Diamond points are employed for grinding holes in dies.

The points consist of a steel core on which a diamond section is applied. The cores are made of alloy steels and heat-treated to Rockwell hardness 47-52 scale *C*. The surface

finish of the end faces of a core should correspond to class 6, whereas the seating places and surfaces to be covered by the diamond layer should be finished to class 7. The diamond section consists of diamond powder and various bonds used in diamond wheels. The layer is applied onto the core either by pressing or by electroplating. Sizes of the diamond points are given in Table 10.13.

Table 10.13

Dimensions of Diamond Grinding Points

Point size	Dimensions, mm				Mass of diamond, carats, for a concentration of	
	outer diameter	diameter of steel core	length of point, *mm*	length of diamond section, *mm*	50%	100%
1	3	2	50	6	0.08	0.16
2	4		50	6	0.15	0.30
3	5		50	6	0.20	0.40
4	5		60	8	0.27	0.54
5	6	3	50	6	0.31	0.62
6	6		60	10	0.50	1.00
7	8		50	6	0.60	1.20
8	8		60	10	1.00	2.00
9	10		60	10	1.60	3.20
10	10		80	16	2.60	5.20
11	12	6	60	10	2.10	4.20
12	12		80	16	3.30	6.60
13	16		80	12	4.80	9.60
14	16		90	20	8.00	16.00

Diamond needle files. Diamond needle files are employed in working intricate profiles of dies and cutting tools.

The needle files consist of a steel core and a diamond section. The cores are made of the same steel as is used for the diamond point cores. The diamond sections consist of a diamond powder of grain sizes 50 to 200 μ and various bonds.

Diamond sticks. Diamond sticks are employed for working parts of dies and measuring tools, as well as for honing operations. The main types and sizes of the sticks are given in Table 10.14.

Table 10.14

Diamond Sticks

Stick shape	Dimensions, mm
General-purpose sticks	
Square	5 × 5 to 10 × 10
Flat	6 × 5 to 10 × 5
Angle	6 × 8 to 10 × 12
Round	Up to 10
Half-round	6 × 5 to 10 × 8
Honing sticks	
Flat	—
Hollowing	11 × 0.2 to 150 × 8

Sticks consist of a steel core and diamond section. The diamond powders differ in grain size. General-purpose sticks have metallic or resinoid bond, but honing sticks are always metal-bonded. The diamond section is applied by electroplating.

Diamond pastes. In recent years, carbide articles and tools have been lapped by means of diamond pastes and powders. Pastes are more efficient and economical than diamond wheels.

Applications of pastes are very diverse: they are used for final lapping operations on parts of high accuracy (1 and 2 classes of accuracy) with high requirements for surface finish (class 10 to 14) and for machining ultrahard and hard materials. If synthetic aluminium oxide and silicon carbide are replaced by diamond powder of the same grain size, the production rate increases two to three times and the surface finish improves.

The diamond pastes given in Table 10.15 are those used now. Diamond grains are bonded in a paste by various materials containing fatty acids, olefinic acid, vaseline or castor oil.

Table 10.15

Diamond Pastes

Grain size	Diamond content in paste, carats, for concentration of diamond powder, %					
	20	10	8	6	4	2
AM40	10.0 25.0 50.0 100.0	—	—	—	—	—
AM28	10.0 25.0 50.0 100.0	5.0 12.5 25.0 50.0	—	—	—	—
AM20	—	5.0 12.5 25.0 50.0	4.0 10.0 20.0 40.0	—	—	—
AM14	—	5.0 12.5 25.0 50.0	4.0 10.0 20.0 40.0	—	—	—
AM10	—	—	4.0 10.0 20.0 40.0	—	—	—
AM7	—	—	—	3.0 7.5 15.0 30.0	—	—
AM5	—	—	—	3.0 7.5 15.0 30.0	2.0 5.0 10.0 20.0	—

Continued

Grain size	Diamond content in paste, carats, for concentration of diamond powder, %					
	20	10	8	6	4	2
AM3	—	—	—	3.0 7.5 15.0 30.0	2.0 5.0 10.0 20.0	1.0 2.5 5.0 10.0
AM1	—	—	—	3.0 7.5 15.0 30.0	2.0 5.0 10.0 20.0	1.0 2.5 5.0 10.0

Laps are made of cast iron, steel, brass, copper, fibre, wood, leather, and felt. Diamond grains are charged onto the lap and the latter is moved for lapping the workpiece.

The diamond concentration in a paste is chosen to suit the grain size of diamonds and the conditions of lapping. Table 10.16 may be useful.

Table 10.16

Paste Consistency Depending on Diamond Concentration in Paste

Grain size	Concentration, per cent	Paste consistency*
AM40	60	T
	40	T, G
	20	G
AM20	40	T, G
	20	T, G
	10	G
AM20	20	G
	10	G
	8	G, L

Continued

Grain size	Concentration, per cent	Paste consistency *
AM14	20	G
	10	G, L
	8	G, L
AM10	10	
AM7	8	G, L
AM5	5	
AM3	8	
	6	G, L
	4	
AM1	6	
	4	G, L
	2	

* T — thick paste, G — grease-like paste, L — liquid paste.

By consistency, diamond pastes are classified as hard (H), thick (T), grease-like (G), and liquid (L).

In the process of lapping, diamond pastes are diluted by lubrication-coolants, for example, by kerosene or oil (vaseline, castor, olive, or sunflower), to the consistency required.

GRINDING WITH ABRASIVE WHEELS

Carbides are ground and finished with vitrified-bonded wheels of green silicon carbide with a grain size of 16-32 and medium-soft hardness (grade CM1 to M3). The wheels are selected in accordance with grinding conditions (Table 10.17).

Feeds and speeds in grinding depend on the grade of carbide.

Table 10.18 gives the peripheral speeds of the abrasive wheel in grinding carbides (the speed of workpiece rotation is 5 to 8 m/min; the rate of traverse, 1 m/min, infeed, 0.02 to 0.05 mm per double stroke).

Table 10.17

Abrasive Wheels for Grinding of Carbides

Operation	Abrasive grain size	Wheel hardness grade
Cylindrical grinding	32-12	CM1-M3
Internal grinding	25-16	CM1-M2
Surface grinding	25-16	M2-M3

Grinding may be carried out dry or wet. The coolant used is 3-5 per cent emulsion with one per cent aqueous solution of triethanolamine. The coolant flow rate is 3 to 5 litres/min.

Carbides can be ground to surface finish of class 7 or 8. If necessary, the surface finish can be improved by lapping.

Table 10.18

Peripheral Speeds, metres per second, of Abrasive Wheels in Grinding of Carbides

Carbide grade	Dry grinding	Wet grinding
T60K6, T30K4	10-15	15-20
T15K6, T14K8	15-20	20-25
BK8, BK6, BK4	15-20	20-25
BK3, BK2	10-15	15-20

Lapping is done with fine-grained resinoid-bonded wheels of green silicon carbide with grain sizes of 8 to 5 and hardness grades M3-CM2. The wheel peripheral speed in lapping depends on the method of machining, and is equal to 20 to 25 m/s when working by the wheel periphery, and 16 to 20 m/s when the wheel face is used. The infeed is within the limits of 0.01 to 0.05 mm per double stroke, the traverse is 0.5 to 2.0 m/min.

When lapping with fine-grained resinoid-bonded abrasive wheels, class 9 or 10 of surface finish is obtained.

Carbides can also be lapped by cast-iron blocks with boron

carbide paste, this eliminating microcracks and ensuring a surface finish of class 8 to 10.

For lapping, the block is charged with a thin layer of paste which includes loose grains of boron carbide. The block is made of fine-grained pearlitic cast iron with a Brinell hardness of 120 to 140. The shape of the block depends on the configuration of the workpiece. Straight, flaring-cup, and dish blocks are generally used. Blocks should be trued at least twice a month.

The force that presses the block to the workpiece ranges from 0.6 to 0.8 kgf/cm^2; the peripheral speed is from 0.8 to 2.0 m/s; and the rate of traverse is from 1.0 to 1.5 m/min.

The quantity of the vehicle, grain size of the powder, and its concentration effect the production rate and quality of lapping of carbide items.

To obtain the surface finish desired, the following boron-carbide powders are used:

(a) class 8—a paste of M40 micropowder or of a grinding powder with a grain size of 5-4, applied on the working part of the block;

(b) class 9—a paste of M14 to M28 micropowder or of a grinding powder with a grain size of 3, deposited on the block in a wet condition;

(c) class 10—a paste of M10 to M7 micropowder deposited on the block in a semi-wet condition.

The vehicle is made of glycerine or paraffin base composition containing 15 to 35 per cent paraffin, 15 per cent oil, and 50 per cent or more kerosene.

The concentration of boron-carbide powder is 40 to 85 per cent, depending on the surface finish desired. Two-thirds of the lapping allowance of 0.08 to 0.15 mm is removed in preliminary lapping, the rest in final lapping.

Lapping is accomplished on special lapping machines.

WORKING WITH DIAMOND WHEELS

Before starting the work,
select and prepare the equipment;
select the operating feeds and speeds;
prepare the workpieces for machining;
select the best machining sequence.

For grinding carbide, diamond wheels with grain sizes A16-A8 are used and for lapping, A6-AM40 wheels are used. For more intensive machining, A32-A20 wheels are employed and for obtaining better surface finish (class 10 and higher) AM14 or finer wheels are used.

Data on cutting variables and diamond-wheel specifications recommended for grinding carbide articles are given in Table 10.19.

Carbides intended for diamond grinding must meet the following requirements:

(1) The parts should have no burrs, cavities, or other defects.

(2) Minimum allowances should be left, not exceeding 0.8 mm for rough grinding, 0.4 mm for finish grinding, and 0.1 mm for lapping.

Steel parts with brazed carbide tips should meet the following requirements:

(1) Carbide tips should overhang by an average of 1 mm over the steel holder.

(2) The diamond wheel, when coming off the carbide tip, should not contact the steel holder to avoid the wheel loading.

(3) After brazing the carbide tip, remove the traces of the solder from the surface.

(4) If there is solder on the surface or the carbide tip is embedded in the holder, grind the surface with silicon carbide wheels before grinding it with diamond wheels.

(5) Perform final grinding and lapping of carbides on the working surfaces only.

Before using a diamond wheel, the upper part of the diamond section is worked over for the diamond grains to project from the bond. Besides, the wheel should be checked for balance. Radial disbalance should not exceed 0.005 to 0.01 mm. All these operations are accomplished by rolling or grinding with abrasive sticks or wheels.

The wheels over 100 mm in diameter should be statically balanced.

In most cases, proper maintenance eliminates wheel dressing and truing. However, in certain conditions the working surface of the wheel may be loaded with metal particles, so that wheel dressing is needed. Wheel is loaded a-

Table 10.19

Cutting Variables and Wheel Specifications Recommended for Wet Grinding and Lapping of Carbides with Diamond Wheels

Type of grinding	Class of surface finish required	Wheel specifications			Machining allowance, mm	Feeds and speeds			
		shape	grain size	bond*		wheel peripheral speed, m/s	speed of workpiece rotation, m/min	traverse, m/min	infeed, mm
Surface	7	Straight	A12-A10	M	0.1-0.2	15-20	—	5.0	0.04
	8		A10-A8					4.0	0.03
	9		A8-A6	O	0.05-0.1	25-35	—	3.0	0.02-0.03
	10		A5-A4					2.0	0.01-0.02
Cylindrical	7	Straight	A12-A10	M	0.1-0.2	15-20	10-20	0.8	0.0075-0.01
	8		A10-A8					0.5	0.0075-0.01
	9		A8-A6	O	0.05-0.1	30-35	20-30	0.5	0.0075-0.01
	10		A5-A4					0.3	0.005-0.0075
Internal	7	Straight wheel or cylindrical point	A12-A10	M	0.1-0.2	10-20	20-30	0.5	0.0076-0.01
	8		A10-A8					0.4	0.005-0.0075
	9		A8-A6	O	0.05-0.1	25-30	15-50	0.4	0.005-0.0075
	10		A5-A4					0.2-0.3	0.005-0.0075
Profile	7	Straight	A12-A10	M	0.01-0.2	20-25	—	1.0-1.5	0.02-0.03
	8		A10-A8						0.02-0.03
	9		A8-A6	O	0.05-0.1	20-27			0.01-0.02

* M — metallic; O — organic.

excessive peripheral speeds, in dry grinding, and when the carbide tip and the steel holder are machined together.

Diamond wheels with organic bonds are trued by soft vitrified-bonded abrasive sticks or wheels of silicon carbide with grain size of 8-16 and hardness grade CM1-CM2, using peripheral speeds of 15 to 25 m/s. Metal-bonded diamond wheels are trued with vitrified wheels of green silicon carbide or white aluminium oxide of grain size 40-25 and hardness

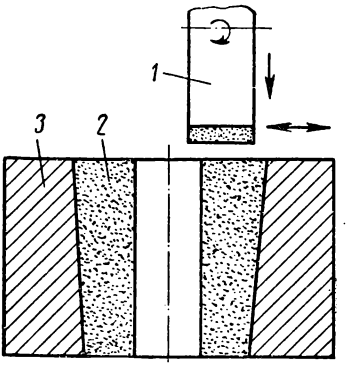


Fig. 10.14. Diamond grinding of carbide articles
1 — wheel; *2* — carbide insert; *3* — die body of steel

grade CM2-CM1, or with vitrified sticks of green silicon carbide with grain size 40-25 and hardness CT1-CT2. When truing metal-bonded wheels, cooling is desirable.

Conditions for trueing of diamond wheels with abrasive wheels are as follows:

Speed of diamond wheel, m/s	working speed
Speed of dressing wheel, m/s	25
Traverse, m/min	1.5-2.0
Infeed, mm per double stroke	0.02-0.04

Diamond wheels are dressed with pumice or vitrified sticks of white aluminium oxide of grain size 16-12, and hardness grade CM2. The dressing tool is firmly secured in a vise or in a special fixture. Heavily loaded metal-bonded wheels are sometimes cleaned chemically with diluted nitric acid. In this case 50 ml HNO_3 (density 1.38) is diluted with one litre of water and the diamond wheel is held in this solution until metal oxides dissolve, after which the wheel

surface is neutralized by keeping the wheel in a solution of 50 g Na_2CO_3 and 100 g $NaNO_2$ in one litre of water for one or two minutes.

The articles that include both steel and carbide are machined (Fig. 10.14) in the direction from the steel to the

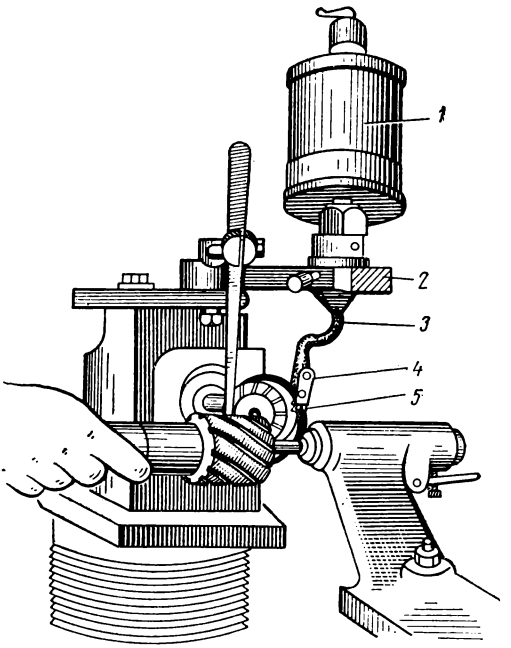


Fig. 10.15. Wheel cooling by wick method
1 — dripper; *2* — bracket; *3* — pipe; *4* — nozzle; *5* — filter

carbide; this decreases the wear of the wheel. The width of the diamond section should be less than the width of the surface being machined.

When machining carbide articles with metal-bonded wheel, grinding at large wheel-to-work contact areas, and grinding steel articles, the diamond wheel must always be cooled. The application of machining fluids improves the surface finish and reduces the wear of diamond grains.

The coolant composition depends on the type of wheel bond. The wheels with organic bonds are cooled by the li-

quid of the following composition: 0.6 per cent trisodium phosphate, 0.05 per cent vaseline oil, 0.3 per cent borax, 0.25 per cent soda ash, 0.1 per cent sodium nitrate, the balance being water.

Instead of a lubricant, a paste containing 67 per cent technical vaseline and 33 per cent paraffin may be applied to the wheel surface.

Alkaline solutions should not be used for lubrication of wheels with organic bonds because they etch the bond.

Metal-bonded wheels are cooled by the liquid of the following composition: 0.4 per cent triethanolamine, 0.4 per cent sodium nitrate, 0.3 per cent trisodium phosphate, 0.3 per cent soda ash, 0.5 per cent borax, 0.1 per cent wetting agent ОП7 or ОП10, the balance being water.

The coolant may be supplied to the wheel as a jet or by means of a wick. When using a wick, a small tank (dripper) is placed on the machine, from which the liquid is fed through a pipe to a felt pad lightly pressed against the wheel surface (Fig. 10.15). In the jet method, the coolant is continuously pumped through a piping, a valve, and a nozzle to the wheel.

The cooling jet contains water (3 to 5 litres/min) with a small quantity (3 to 5 per cent) of light oil (e.g., spindle oil) introduced to prevent corrosion of the metal. The wick method used for metal-bonded wheels requires a liquid containing 66.5 per cent kerosene and 33.5 per cent machine oil.

WORKING OF CARBIDES WITH DIAMOND PASTES

Finishing and lapping of carbides is done with diamond powders and pastes, whereas steel, nonferrous, and carbide articles are processed with powders of silicon carbide and synthetic aluminium oxide.

In accordance to the method of abrasive supply, the following methods of finishing are known:

(1) Finishing with a continuous supply of the abrasive mixture. In this case the mixture, which is a suspension with a low abrasive content, is poured into a tank and then pumped to the working surface of the lap and workpiece. A high production rate is obtained, but the accuracy and surface finish are not very good.

(2) Finishing with the abrasive mixture applied to the lap. Thick mixtures with a higher abrasive content or special pastes are used. The mixture is applied to the lap by a brush or pad, then the abrasive powder is deposited over it and liquid is poured over it; the abrasive mixture is smoothed out on the lap surface until a thin layer is obtained. After completing a cycle of finishing the mixture is removed, a new mixture is applied, and the cycle is repeated. This method is less productive, but the dimensional accuracy is better.

In the two cases mentioned above, most of the abrasive grains are loose in the clearance between the lap and the workpiece, and they move independently of one another.

(3) Finishing by charged laps. The laps are made of pearlitic or pearlitic-ferritic cast iron. Abrasive grains penetrate into the ferritic areas of cast iron. When charging of the lap is completed, a thin layer of lubricant is applied.

In this case the surface of the workpiece is machined by fixed abrasive grains as when using abrasive wheels and sticks. Finishing with charged laps is the least productive method but it ensures a high accuracy (flatness and parallelism to within 0.1 to 0.2μ) and a surface finish of class 13 to 14.

Depending on the nature of the part being machined, there are the following types of lapping operations:

(a) flat lapping of one plane of the part;

(b) plane-parallel lapping of two opposite planes simultaneously;

(c) flat lapping of cylindrical parts;

(d) lapping of external cylindrical and conical surfaces;

(e) lapping of holes;

(f) lapping of profile surfaces, such as spheres, threads, or gear teeth.

By the accuracy and surface finish, finishing operations are classified as:

coarse (allowance 0.02 to 0.05 mm, accuracy 3 to 5μ, surface finish to class 9 or 10);

smooth (allowance 0.005 to 0.01 mm, accuracy 1 to 2μ, surface finish to class 10 or 11);

fine (allowance 0.0003 to 0.001 mm, accuracy 0.1 to 0.5μ, surface finish to class 12 to 14).

When using pastes, the following requirements must be met:

1. Diamond paste should be applied only after careful preliminary machining and cleaning of the carbide articles. This purpose is best achieved by grinding with diamond wheels. If the shape of the part does not allow surface, cylindrical, or profile grinding, employ a diamond needle file.

2. The class of surface finish after lapping depends on the grain size of the diamond paste used, therefore, to achieve the surface finish desired, use several pastes, applying successfully ever finer pastes.

3. The lap can be made of cast iron, steel, brass, copper, fibre, wood, leather, and felt. The lap material is chosen to suit the workpiece hardness and surface finish desired. In addition, the following factors should be considered:

(a) the lap should be softer than the material to be machined;

(b) the rougher is the part surface after preliminary machining, the greater is the allowance necessary for lapping, the coarser the diamond grains, and the greater the hardness of the lap;

(c) when using fine-grained diamond pastes, a higher quality of surface finish is achieved with softer laps;

(d) when using pastes of the same grain size, different results may be obtained because of different lap hardness, the best results being attained with cast-iron laps.

4. Diamond paste may be applied to the lap or to the workpiece. It is preferable to work with a small quantity of diamond paste, because a large number of diamond grains hinders lapping.

5. Powders should be carefully classified in size. A paste should not be contaminated with coarser grains, as these may cause deep notches on the lapped surface. Employ a special lap for each paste and mark it with its grain size number.

6. Diamond pastes may be used for both manual and machine lapping, but machine lapping gives better results.

The best conditions of lapping are lap speed, 3 to 6 m/min, pressure, 3 to 5 kgf/cm^2.

The factors important for carbide lapping with pastes of different grain size are given in Table 10.20.

Table 10.20

Lapping Carbides with Pastes of Different Grain Sizes

Grain size	Cutting rate, μ/min	Paste consumption, mg/g	Class of surface finish
AM40-AM20	35-50	1.0-1.5	8-10
AM14-AM5	8-25	0.8-1.0	9-11
AM3-AM1	2-8	0.1-0.4	10-13

CHAPTER XI

Grinding and Finishing Sintered-Carbide Tools

11.1. Fundamentals of Tool Grinding

Parts are machined with cutting tools, such as cutters, drills, counterbores, reamers, broaches, milling cutters, screw taps and dies, and gear-wheel cutters.

In the course of using a tool, its cutting edges wear out and thus get blunted. As the cutting tool becomes blunt, the productive capacity of the machine tool is reduced, and the form of the part being machined is distorted; therefore, the geometrical parameters of the cutting tool will have to be periodically restored.

The form of cutting and boring tools is restored by grinding them on various grinding machines, using abrasive and diamond wheels.

GEOMETRICAL PARAMETERS OF GRINDING TOOLS

In spite of the great variety of different tools available, they possess common geometrical elements. Any cutting tool has a working part comprising one or multiple cutting edges such as: face (top surface), side flank, front flank, side cutting edge, front cutting edge, second front cutting edge, and cross edge (Fig. 11.1). A cutter has but one side cutting edge; a drill, two cutting edges; a counterbore, reamer, broach, and a milling cutter has multiple cutting edges.

Beside the working part, the tool is characterized by its cutting part. The cutting part of a tool is understood to be constituted by such elements as the form of the face and flank of a tool, its top-rake and side-rake, and its cutting edges.

The angles of the cutting part of a tool are measured in the main and auxiliary sectional planes, as well as in the

base plane. According to the plane under consideration, the angles are subdivided into end relief and end cutting angles, and plan trail angles.

The angles of the working part of cutting tools are diagrammatically represented in Fig. 11.2.

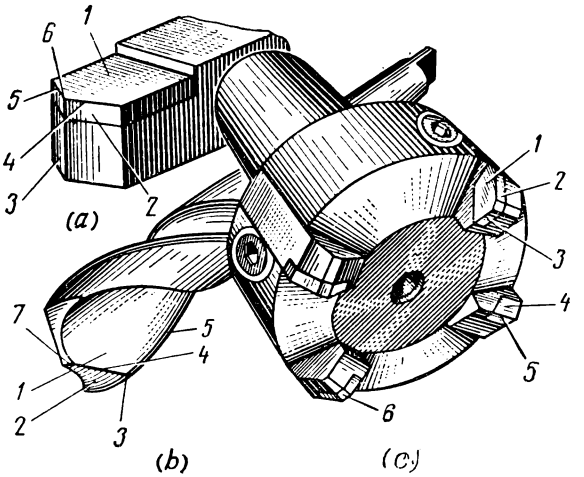


Fig. 11.1. Main elements of the working part of cutting tools (*a*) cutter; (*b*) spiral drill; (*c*) end mill; *1* — face; *2* — side flank; *3* — front flank; *4* — side cutting edge; *5* — front cutting edge; *6* — second front cutting edge; *7* — transverse cutting edge (cross edge)

The forms of the face and flank of a cutting tool are selected depending on the material being machined, type of tool, and the material the working part is made of.

The form and dimensions of the working part of cutting tools are obtained by grinding and finishing the corresponding surfaces of the tools.

To guarantee the desired shape and angles formed by the face and flank, the cutting tools are ground on the surfaces of their working part. The grinding pattern is adopted according to the type of tool used and conditions of its operation.

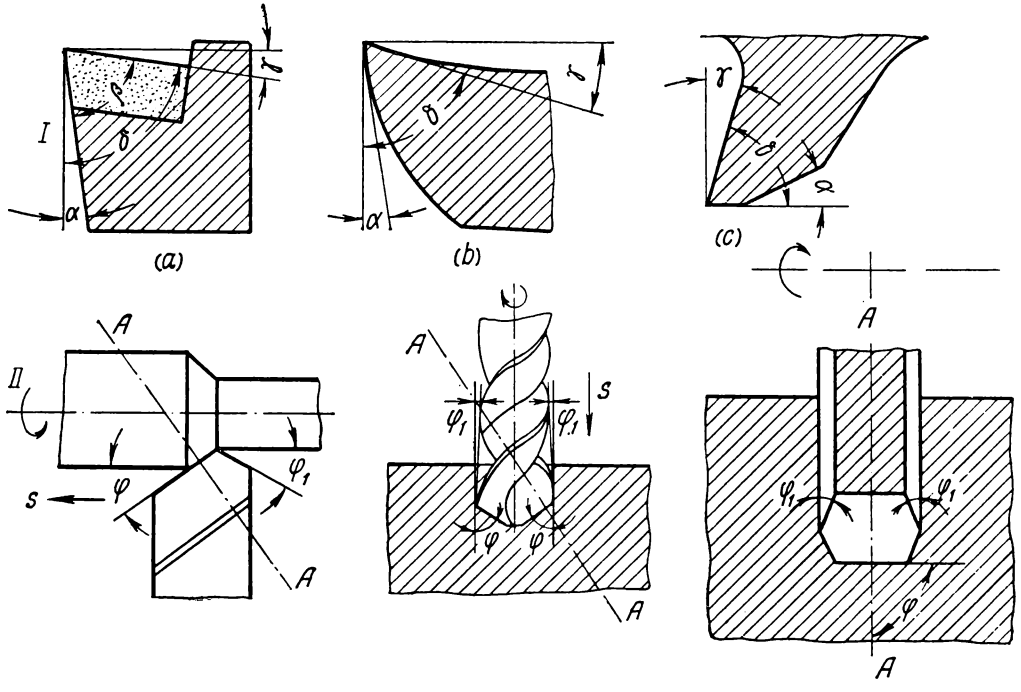


Fig. 11.2. Angles of working part of cutting tools

I — angles in main section *A*-*A*; *II* — angles in plan (*a* — cutter; *b* — spiral drill; *c* — slot mill); α — primary back clearance angle; β — angle of taper; γ — rake; δ — cutting angle; φ — primary back clearance angle in plan; φ_1 — secondary clearance

11.2. Grinding Machines

According to the type of work done and their design, grinding machines may be subdivided into:

(a) general-purpose machines;
(b) universal grinders;
(c) special-purpose grinders.

The general-purpose machines are generally one- or two-sided grinders that are equipped with devices for clamping and fixing tools. In these machines, the grinding wheel is only capable of rotating, either directly from an electromotor or through the medium of a belt transmission. Grinding machines of this type are mainly employed for sharpening single-cutting edge tools. During the course of grinding, the tool being sharpened is moved by hand along the tool rest both in the transverse and longitudinal directions.

Universal grinders are employed for sharpening various tools. These machines are characterized by the possibility of positioning the tool surfaces in the process of their grinding by means of transferring the tool relative to the wheel in three directions perpendicular to each other, namely: vertically, by lifting the grinding head or table; horizontally, the longitudinal and transverse travel of the table. Moreover, in these machines, both the grinding head and upper table are capable of rotating about their vertical axes.

The grinders are equipped with standard and special devices that are intended for setting and fixing tools. All this makes it possible to sharpen tools having various working surfaces, such as cutters, drills, milling cutters, broaches, gear cutters, etc.

Special-purpose grinders are intended for grinding tools of only one type. In the course of grinding, both the tool and grinding wheel perform certain constant motions that are required for grinding a given tool. Special-purpose grinders may be made with hand feed, when the tool is moved relative to the wheel by hand; they may be semi-automatic, when sharpening is effected automatically, whereas the tool being ground is set and removed by hand; and automatic, when all the grinding operations are fully automated.

Boring tools are most frequently ground on general-purpose grinding machines. Special-purpose grinders are also

employed for this purpose and recently there have been developed designs of automatic grinders.

Special finishing machines are applied for finishing single-edge sintered-carbide cutting tools; usually a single-spindle finishing machine with a horizontally positioned spindle is used. On this machine the finishing operation may be effected either mechanically or manually.

To finish multiple-edge tools, there are employed universal grinders equipped with the same devices as those used for grinding single-edge tools.

11.3. Selection of Grinding-Wheel Characteristics, and Speed of Abrasive and Diamond Grinding of Sintered-Carbide Tools

Green silicon carbide and black silicon carbide abrasives are commonly used for grinding sintered-carbide tools; silicon carbide wheels are used for grinding the tip, whereas wheels made of synthetic corundum are used for grinding the steel holder of the cutting tool. Recently, diamond wheels have come to be extensively used for grinding and, especially, for lapping sintered-carbide tools.

The grain size of the abrasive material affects the grinding speed and the degree of surface finish. For grinding sintered-carbide tools the most effective abrasive wheels are those made of green silicon carbide having a grit size of 25 to 16, that guarantee maximum removal of stock and good-quality surface at minimum grinding costs. Tools may be previously ground with coarser grit abrasive wheels of a grain size of 40.

The selection of the hardness of an abrasive wheel is determined by its cutting action and self-sharpening ability; therefore, when grinding sintered-carbide and mineral-ceramic tools, use is made of softer wheels (grades M1, M2, M3, and CM1) in the case of a ceramic bond, and by 1 or 2 degrees harder in the case of a bakelite bond. Whenever it is necessary to obtain a more accurate size and form of the tool being ground, harder abrasive wheels are employed.

Tools fitted with sintered-carbide or mineral-ceramic tips, are ground by means of abrasive wheels made on ceramic or bakelite bonds. Grinding wheels made on a ceramic

bond are more resistant to wear, but more brittle, than wheels made on a bakelite bond. When using wheels made on a bakelite bond for grinding cutters, drills, reamers, etc., the grinding speed is increased by 150 to 200 per cent, while the surface finish is higher by one or two classes. Because of that, in spite of the increased wear of grinding wheels made on a bakelite bond, their employment is desirable. Moreover, when using these wheels, the rotational speed of a grinding wheel should be increased up to 25 to 35 metres per second, i.e., the grinding efficiency increases, too. It is common practice to employ wheels made on a bakelite bond, with a grain size of 40 to 16, for grinding; and those with a grain size of 6 to 4 for lapping a tool.

The structure of the abrasive determines the amount of free space between the grains. When grinding sintered-carbide and mineral-ceramic tools, it is desirable to apply wheels having more free space between the grains, which facilitates the removal of chip from the cutting zone, reduces the possibility of burns occurring, and facilitates cooling of the tool being ground. When grinding with diamond wheels, there are mainly employed grinding wheels made of artificial diamonds on a metal or organic bond.

Diamond wheels with a concentration of 50 per cent are employed for finishing grinding; of 100 per cent and higher, for rough or preliminary grinding; and of 25 per cent (made only on an organic bond), solely for lapping tools.

Different speeds of grinding of sintered-carbide and mineral-ceramic tools are dependent on the characteristics of the grinding wheels employed. The grinding speeds are especially dependent on the grinding material (silicon carbide or diamond), and the type of bond used (ceramic, metal, organic). Only the selection of the correct characteristics of the grinding wheel and the most suitable speed of grinding guarantees high efficiency and good quality in grinding a tool.

The grinding speed is made up of the rotational speed of the grinding wheel, rotational speed of the tool being ground, and rates of longitudinal and transverse feed; they depend on the characteristics of the grinding wheel employed, material the tool is made of (sintered carbides, mineral-ceramics), and design of the tool (single-edge, multiple-edge).

11.4. Selection of Characteristics of Lapping Materials and Speed of Lapping Sintered-Carbide Tools

After finishing the grinding operation, the sintered-carbide tool is lapped in order to obtain tools with the specified dimensions and an even, smooth surface of the sintered carbide. The lapping of a tool is necessitated by the fact that even finishing grinding is not capable of assuring the correct geometrical shape of the tool, and of removing the unevenness from its working part. The lapping operation increases the resistance of a cutting tool by as much as 25 to 100 per cent.

Sintered-carbide cutting tools are lapped in two ways, by means of:

(a) fine-grain abrasive and diamond wheels or whet-stones;

(b) pastes or mixtures, in which the grains of the abrasive (or diamond) are loose (not held together by a bond).

When lapping with fine-grit abrasive and diamond tools, only a thin layer of the material being abraded is removed. Lapping is effected with small rates of transverse and longitudinal feed, which contributes to removing microroughness and attaining rectilinear cutting edges.

Especially effective is the lapping of a sintered-carbide tool with diamond grains; this method of lapping is employed where a high accuracy of the cutting tool is required.

Figure 11.3 diagrammatically illustrates lapping a tool by both methods.

Lapping according to the first method is effected on ordinary grinders, whereas in the second method (with the use of loose grains), iron discs are employed. It is common practice to use a fine-grained iron disc of pearlitic structure having a Brinell hardness number of 120 to 140, which rotates at a speed of 2.5 to 1.5 metres per second. When lapping a tool with loose grains, there is no increase in the temperature in the cutting zone, which obviates burning of the material and the appearance of microcracks.

In both methods the lapping of sintered-carbide cutting tools is effected along a narrow band 2 to 3 mm wide.

Recently there has been noted a steadily growing application of electrodiamond lapping of sintered-carbide cutting tools with the aid of special current-conducting wheels

made on a metal bond. Electrodiamond lapping is capable of ensuring a surface finish not lower than the 10th class.

Table 11.1 represents the characteristics of wheels and abrasive materials employed for lapping tools.

The following recommendations should also be observed:

(a) when removing a large allowance (excessive stock), lapping should be conducted in two operations: preliminary,

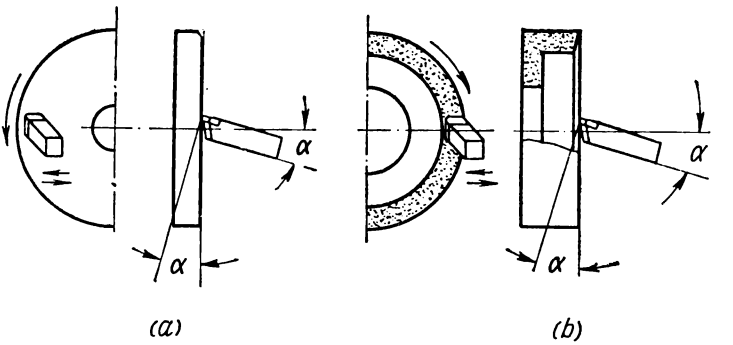


Fig. 11.3. Schematic drawing showing the setting of a cutter when lapping it
(*a*) with loose abrasive grains; (*b*) with grinding wheels

with the use of coarser grain abrasives; and finishing, with fine grain abrasives;

(b) it is necessary to apply lapping wheels and discs of the maximum sizes allowable by the design of the machine used and the tool being lapped;

(c) in hand lapping, flat whet-stones should be used;

(d) lapping discs should be made of grey iron having a pearlitic structure with a Brinell hardness number within the range of 130 to 160 and the following chemical composition (per cent): carbon, 3-3.5; silicon, 3-4; manganese, 0.6-0.8; phosphorus, 0.8-1.0; and sulphur, 0.1.

The speeds of lapping tools, when abrasive wheels and when pastes are used, are set forth in Table 11.2.

When lapping with diamond wheels, it is recommended that the same emulsion be used as that employed in diamond grinding.

Table 11.1

Characteristics of Grinding Wheels and Abrasive Materials for Lapping Cutting Tools

Tools to be treated		Lapping by means of								
		paste and solutions					grinding wheels			
				lapping disc						
description	material of the cutting part	main abrasive material	grain size*	form	diameter, mm	height, mm	characteristics**	form	diameter, mm
Single-cutting edge tools: cutters, knives for composite milling cutters, gear cutters	Sintered carbides and mineral-ceramics	Diamond Boron carbide Silicon carbide	ACM4-ACM1 6-M7 6-M28	Flat, straight profile (FS)	250-300 or according to machine used	25-30	КЗ (6-5) СМ2Б АС6-АСМ40 100% О	FS, CC	125-150
	Tool steel	Chromium oxide Natural or synthetic corundum Silicon carbide	3-M1 5-M7				(КЗ-КЧ) (6-5) С1-СМ1Б АС8-АС3 100% О		
Multiple-cutting edge tools: reamers, milling cutters with pointed and relieved blades, broaches, shaped cutters	Sintered carbides	Diamond Boron carbide	ACM4-ACM1 6-M7	Conical cup (CC) Plate (P)	50-150	5-15	КЗ (6-5) СМ2Б АС6-АСМ40 50% О	CC, CC, P	50-150
	Tool steel	Chromium oxide Natural or synthetic corundum	3-M1 5-M7				(КЗ-КЧ) (6-3) С1-СМ1-Б АС8-АС3 100% О		

* The Russian letters denote different grits.
** The Russian letters denote different grades of silicon carbide and diamond wheels.

Table 11.2

Speed of Lapping Cutting Tools

Tools and materials	Material the tool cutting part is made of	Lapping speed			
		speed of wheel (disc), m/s	effort in lapping, kgf	rate of transverse feed, mm/double run	rate of longitudinal feed, m/min
Abrasive wheel	High-speed steel, sintered carbides	30-35	—	0.015-0.05	1.5-2.0
Paste and abrasive mixture	High-speed steel, sintered carbides	1.5-3.0	0.75-1	—	1.0-1.5
Diamond wheel	High-speed steel	15-18	—	0.005-0.01	0.2-0.75
Diamond wheel	Sintered carbide	30-35	—	0.005-0.01	0.2-0.75
Diamond paste and powder	Sintered carbide	1.5-2.5	0.75-1	—	1.0-2.0

11.5. Procedures for Grinding and Lapping Sintered-Carbide Tools

There are three different processes employed for grinding and lapping sintered-carbide tools:

1. The abrasive process consisting in:

(a) grinding the steel holder with a wheel made of synthetic corundum;

(b) pregrinding the sintered-carbide tip on its face and flank with a grinding wheel made of silicon carbide;

(c) finishing grinding of sintered-carbide tips with wheels made of silicon carbide;

(d) lapping the tip edge with a fine-grained paste made of boron carbide, or with fine-grained wheels made of silicon carbide (on a bakelite or ceramic bond).

2. The diamond-abrasive process consisting in:

(a) grinding the steel holder with a wheel made of synthetic corundum;

(b) pregrinding the sintered-carbide tip with a grinding wheel made of silicon carbide;

(c) finishing grinding of sintered-carbide tips with wheels made of silicon carbide or a diamond wheel on a metal bond;

(d) lapping cutting edges with a fine-grained diamond made on an organic bond.

3. The diamond process consisting in:

(a) pregrinding the steel holder and removing solder from the sintered-carbide tip with the aid of wheels made of synthetic corundum;

(b) pregrinding sintered-carbide tips with a diamond wheel made on a metal bond.

(c) finishing grinding of sintered-carbide tips with a diamond wheel made on a metal or organic bond;

(d) lapping the cutting edges with a fine-grained diamond wheel made on an organic bond.

11.6. Maintenance of Grinding Equipment and Tools

INSPECTION OF QUALITY OF GRINDING WHEELS

Inspection of the quality of grinding wheels comprises several operations.

Visual examination of grinding wheels. Abrasive wheels, prior to mounting them on a machine, are examined and

checked to establish whether there are any cracks or dents. Wheels more than 50 mm in diameter should be checked by tapping them lightly with a wooden mallet on their lateral surface. Good-quality wheels emit thereby a pure sound, whereas faulty wheels (with cracks), a rattling sound.

Testing for mechanical strength. Prior to setting them on the spindle of a grinding machine, wheels 150 mm in diameter and greater, that are intended to operate at a speed of 15 m/s and faster, as well as wheels more than 30 mm in diameter, rotating at a speed of 40 m/s and faster, should be tested for their mechanical strength at a rotational speed exceeding the working speed by 50 per cent. The duration of testing marked wheels should be as follows:

Outer diameter of wheel, mm	Duration, minutes
30-150	3.0
150-475	5.0
500 and more	7.0

Grinding wheels more than 150 mm in diameter, the marking of which does not contain any indications as to the allowable working speed, as well as wheels that have been mechanically altered or chemically treated, should be tested for a period of 10 minutes at a rotational speed exceeding the working speed by 60 per cent.

Prior to being mounted on a grinding machine, all new wheels, as well as those that have been subjected to mechanical or chemical treatment, have to be tested. Each wheel, which has successfully passed the test, is marked to the effect that it is suitable for work.

Testing for hardness. The hardness of grinding wheels made on a ceramic or bakelite bond, of a grain size within the range of 50 to 12, is determined by measuring the depth of the indentation produced on the wheel surface by the pressure exerted on it by a stream of quartz sand emitted from a sand-blast apparatus.

The hardness of grinding wheels made on a ceramic or bakelite bond, of a grain size within the range of 12 to 40, is determined by measuring the depth of penetration of a steel ball under a constant load on a Rockwell testing machine.

Grinding wheels made on a vulcanite (hard rubber) bond, having a grain size within the range of 10 to 50, are tested by determining the number of revolutions that are required for drilling in the wheel a hole of a certain depth, the drilling operation being performed on a special device.

The technique of testing wheels for hardness consists of the following operations: the wheel is placed on the machine table so that the testing zone is located immediately under the spindle or nozzle of the instrument. The testing zone is defined according to the shape and dimensions of the wheel to be tested, on its end face at a distance of 10 to 15 mm from the periphery of the wheel, and at a distance of 20 to 30 mm from its inner (central) hole. The hardness is measured in four diametrically opposite zones; two zones should be located at the wheel periphery, and two zones at the hole rim. The hardness of the wheel is determined as the arithmetic mean of data on the hole depth and number of revolutions obtained in all the four tests.

BALANCING GRINDING WHEELS

When setting a wheel on the machine spindle, it should be subjected to balancing; in the course of operation, the wheel must be periodically checked for out-of-balance. Grinding wheels more than 125 mm in diameter must always be subjected to balancing.

A balanced or equilibrated abrasive wheel is considered to be one, whose centre of gravity coincides with its geometrical centre. At present there is employed for this purpose a method of static and dynamic balancing.

Static balancing of a wheel. Static unbalance is determined on a balancing apparatus, the main part of which consists of two steel cylindrical shafts of the same diameter, that are arranged parallel to each other and have a smooth surface finish not lower than the 9th class (Fig. 11.4). The wheel is secured on a steel balancing mandrel with the aid of a conical bushing or four-support cross-piece, which is tightly inserted in the wheel hole. The balancing mandrel together with the conical bushing or four-support cross-piece should be previously balanced. Contacting with the shafts of the balancing apparatus is the surface of the

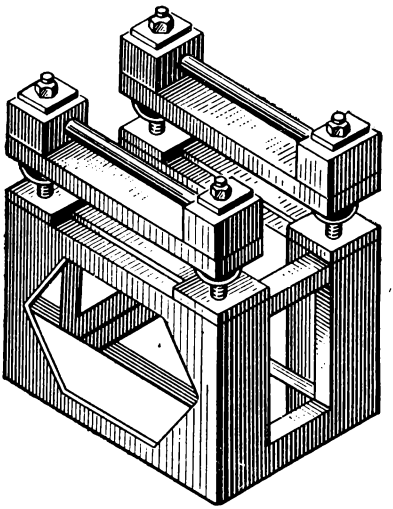


Fig. 11.4. Apparatus for statical balancing of abrasive wheels

balancing mandrel, which should be finished to not lower than the 8th class. The cross-piece is cast of an aluminium alloy. Steel inserts are provided at the points of contact between the cross-piece and the walls of the central hole of the wheel.

Prior to measuring out-of-balance, the shafts of the balancing apparatus are placed horizontally (Fig. 11.5). The wheel together with the mandrel is placed on the balanc-

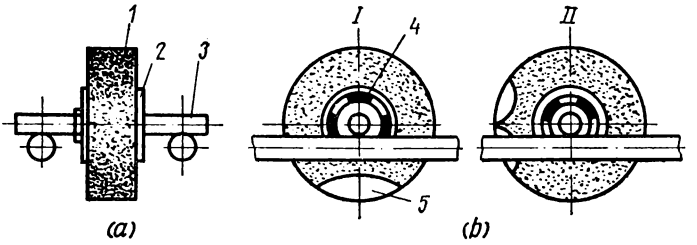


Fig. 11.5. Position of wheel during its balancing

(*a*) initial position; (*b*) moment of balancing the wheel; *1* — wheel; *2* — chuck; *3* — mandrel; *4* — slide blocks; *5* — heavy part of the wheel

ing apparatus so that the axis of the balancing mandrel is perpendicular to the shafts of the apparatus, and the wheel is set symmetrically between them. The wheel is made to rotate slowly by pushing it slightly. After the wheel has come to a stop (position *I*), the upper point of its periphery is marked, and a clamp is attached at this point. After that the wheel is put into position *II* by turning it through an angle of 90 degrees relative to position *I*; then at its periphery, with the aid of a clamp, such a load is fixed,

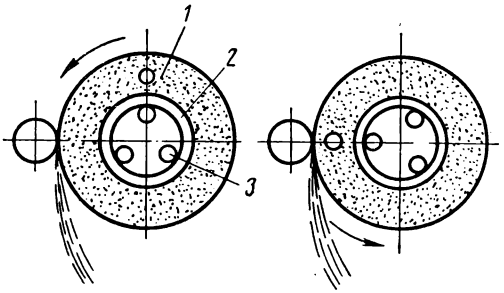


Fig. 11.6. Schematic drawing illustrating dynamic balancing of wheels with the aid of balls

which sets the wheel in equilibrium, at which the wheel, after a number of light pushes, stops in various positions. This load is the static unbalance of the wheel.

If it is necessary to determine or check the class of out-of-balance, it will be sufficient to attach the maximum load of this class onto the wheel in position *II*. If the wheel, under the effect of this load, remains at rest or goes down, it meets the requirements of unbalance of the given class; if the wheel goes up, it does not meet these requirements.

When balancing a wheel, it is equilibrated by means of slide blocks *4* provided on balancing flanges. If the weight of the slide blocks proves to be insufficient for eliminating the unbalance of the wheel, it should be reground.

Dynamic balancing. Dynamic balancing is resorted to when the diameter of the wheel exceeds 300 mm.

There are several methods of dynamic balancing, but the one most frequently employed is the method of balancing by means of balls.

Figure 11.6 is a schematic drawing of dynamic balancing of wheels with the aid of balls. Placed in chuck *2* of grinding wheel *1* are three balls *3* that during the balancing of the wheel are automatically positioned so that unbalance is eliminated, whereupon the balls are clamped in the chuck by means of a special locking device.

MOUNTING GRINDING WHEELS

Protective hoods. Prior to setting a wheel on the spindle, it should be tested by rotation and marked; high-speed wheels must be additionally marked with a red stripe or the inscription 'high-speed'.

On grinding machines, that are not assigned to a particular worker, the wheel is set by specially skilled workers; if the grinding machine is assigned to a given operator, he himself is in charge of mounting the wheel.

Prior to mounting a wheel, it is necessary to check whether the actual rotational speed of the spindle corresponds to the speed allowable for the given wheel.

The wheel should easily be fitted on the machine spindle; no effort should be exerted when doing this. Between the wheel hole and the diameter of the fitting area on the spindle there should be a clearance which depends on the diameter of the wheel hole (see Table 11.3).

Table 11.3

Clearance Between Diameter of Wheel Hole and Diameter of Fitting Area of Spindle

Diameter of the wheel hole, mm	Clearance, mm, for grinding wheels:	
	high-speed	ordinary speed
Up to 100	0.1-0.5	0.1-0.8
101-250	0.2-0.6	0.2-1.0
Over 250	0.2-0.8	0.2-1.2

If the wheel hole is smaller than the spindle diameter, the former should be additionally bored; if the hole is too large, the wheel should be provided with a bushing,

or the hole is partly filled in with a specially prepared compound.

When mounting a wheel on a machine, it is fixed with flanges. Between the flanges and the wheel, it is necessary to provide packings of an elastic material (such as close-texture paper, carboard, rubber) 0.5 to 1.0 mm in thickness. Such packings should cover the entire clamping surface of the flange and overlap the edge of the flange, along the entire circumference, by not less than 1 mm.

The diameter and dimensions of the end surfaces of the flanges, clamping the wheel, should be equal. The diameter of the fixing flanges should approximately be equal to $^1/_2$—$^2/_3$ of the wheel diameter. Provided on the inner side of the flanges is a recess, and the flanges contact the wheel along an annular surface, the width of which ranges from $^1/_8$ to $^1/_{16}$ of the flange diameter.

When centering the wheel on the spindle prior to its final fixing thereon, it is only permitted to tap the wheel lightly with the hand or a wooden mallet. When fixing the wheel, the nuts should be tightened up by hand, using only a wrench of the appropriate size. It is prohibited to employ striking tools or to build-up the wrench. The screw and nuts of the flanges that are arranged in pairs on diametrically opposite sides, should be tightened up successively and gradually.

It is not permitted to set a wheel on a spindle with a radial play of more than 0.03 to 0.05 mm.

After the wheel has been mounted on a grinding machine, it should be tested by idle running for 5 minutes at the working speed, with a view to checking the wheel strength and the absence of play. During testing, it is prohibited to stand opposite the open part of the hood.

To protect the personnel against wheel chips and abrasive particles, protective hoods are provided on the grinding machine. The minimum thickness of the hood walls depends on the diameter and height of the wheel used.

The hood should cover the entire non-working part of the spindle and flanges. There are standards existing, specifying the arrangement and maximum admissible angles of opening the hood under various operating conditions of the grinding wheel.

Stated below are the values of the gaps between the grinding wheel and the inner cylindrical surface of the protective hood:

Wheel diameter, mm	Up to 100	101-300	301-600	751-1400
Gap, mm, not more than	9	10	15	20

The gap between the lateral side of the protective hood and the flanges for fixing a wheel of the greatest height used in the given machine should be within the range of 5 to 10 mm. The gap between the grinding wheel and the protective visor should not exceed 6 mm.

Simple grinders or sharpeners are provided with transparent shields and tool rests for supporting and fixing the tools to be ground.

DRESSING GRINDING WHEELS

Grinding wheels are dressed for ensuring a maximum productive capacity, high surface finish as well as accuracy of the surface being ground. Dressing is carried out after

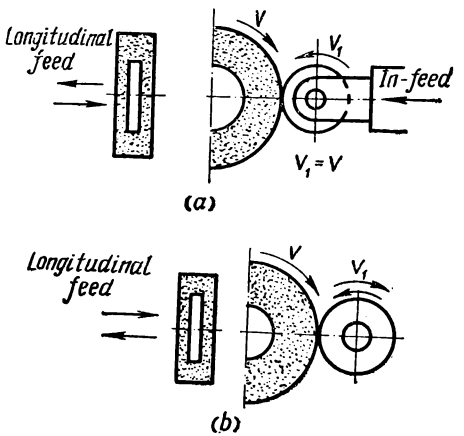


Fig. 11.7. Schematic drawing illustrating the methods of dressing a grinding wheel
(*a*) running-in method; (*b*) grinding method

the wheel grains have been blunted or glazed; in case the wheel shape has been distorted due to dents and cracks; and when it is necessary to change the shape of the wheel

if the ground surface proves to be insufficiently accurate and of poor quality.

All the operations of dressing grinding wheels are effected either by means of running-in or of grinding (Fig. 11.7).

When dressing by the running-in method, the grinding wheel is rotated at the working speed, while the dressing wheel is driven by the forces of friction developing between the contacting wheels. The rotational speed of the dressing wheel is somewhat slower than that of the grinding one.

Dressing by the grinding method is carried out in the same way as the grinding process. The dressing wheel is

Table 11.4

Characteristics of Diamond-Metal Pencils

Type of pencil	Grade of pencil*	Mass of separate diamonds, carats or fineness No. of diamond	The total mass of diamonds in a pencil		Number of diamonds in a layer
			carats	permissible deviations	
C	ОС	1/5-1/10	1.0	±0.02	2-4
	СМ	1/10-1/20	1.0	±0.02	4-5
H	НИМ	1/120-1/450	1.0	±0.02	—
	НВМ-36	No. 36	0.5	±0.02	—
	НВМ-46	No. 46	0.5	±0.02	—
	НВМ-60	No. 60	0.5	±0.02	—
	НВМ-80	No. 80	0.5	±0.02	—
	НВМ-100	No. 100	0.5	±0.02	—
Ц	ЦК	0.85-0.5	Actual mass of the diamond grain		
	ЦС	1/2-1/5	1	±0.02	1
	ЦМ	1/5-1/10	0.5	±0.02	1
	ЦВМ	1/10-1/20	0.5	±0.02	1
	ЦВМУ	1/10-1/20	0.5	±0.02	1
	ЦВМ	1/20-1/30	0.5	±0.02	1

* According to USSR Standard 607-56

fitted on a mandrel and is set in the machine centres; it is forced to rotate either by a separate motor or by a headstock drive.

The facilities available for dressing include: diamond-metal pencils, sintered carbide monolithic smooth discs mounted

Table 11.5

Permissible Maximum Peripheral Speed of Grinding Wheels

Wheel	Speed of wheel, m/s, depending on the bond used		
	ceramic	bakelite	vulcanite (a hard rubber)
Flat, straight profile			
For roughing and grinding operations (1)*, and for outer cylindrical grinding	50	50	—
Wheels 300 to 750 mm in diameter, up to 75 mm in height (2)*, for internal cylindrical grinding	50	50	42
Wheels 30 to 90 mm in diameter, up to 50 mm in height (2)*, for internal cylindrical grinding	50	—	—
Wheels up to 80 mm in diameter (2) for cutting and grinding thread	65	—	—
Wheels with a grit size of 100 and finer, $400 \times 10 \times 203$ in size	55	55	—
Flat, with a two-sided conical profile			
For cutting and grinding thread, having a grain size of 100 and finer (3)*, with dimensions, in mm:			
$450 \times 8 \times 229$	55	—	—
$450 \times 10 \times 229$	55	—	—
$500 \times 10 \times 254$	55	—	—
$350 \times 8 \times 160$	42	—	—

* Conventional designations of feed: (1) – by hand; (2) – mechanical or automatic; (3) – automatic.

in ball bearings, discs made of sintered carbide crumbs and mounted in ball bearings, discs made of silicon carbide, corrugated iron discs, and steel sprockets.

The most extensively used means for dressing grinding wheels are the diamond-metal pencils. They are manufactured as diamond-metal inserts press-fitted in special holders.

Depending on the arrangement of the diamonds, the pencils are manufactured in three types: type С, in which the grains are arranged in layers; type II, in which the grains are distributed at random; and type Ц, in which the grains are arranged in a chain-like pattern.

Table 11.4 gives the characteristics of diamond-metal pencils that are industrially produced. The grade of a pencil should be deciphered in the following manner: the first letter designates its type, while the following letters and figures designate the size of the diamonds: К — large, С — medium, М — small, НМ — the smallest, НМУ — the smallest of an elongated form, and ВМ — extremely fine.

The maximum permissible speeds of rotation of the grinding wheels are presented in Table 11.5.

CHAPTER XII

Applications of Sintered Carbides in Mining

12.1. Methods of Boring Blast-Holes and Boreholes

Various boring machines used in the mining industry have carbide tips fitted for boring blast-holes and boreholes.

The boring equipment and tools required are chosen according to the method of boring. The mode of tool working characterizes the boring processes which may be divided into rotary, rotary-percussion, percussion-rotary, and percussion boring.

Rotary boring requires considerable torque and a large axial force applied to the boring tool, which destroys the rock by the shearing forces. Rotary boring is carried out with the help of electric drills and boring cutter machines.

In percussion boring the tool after each percussion rebounds, turns and strikes again. Percussion boring is accomplished with drills or drilling rigs with drills.

In rotary-percussion boring, the rock is destroyed by the action of the impact load and torque, i.e., by impact and shear. In this case rotary boring percussion-action machines are used. Self-propelled trucks are used for boring because large axial forces are required.

In percussion-rotary boring the rock is also destroyed as a result of shear and impact. Boreholes are bored with pneumatic percussion drill units or drills with independent rotation of drill. In the first case the pneumatic percussion drill is lowered into the borehole; in the second case the drill remains on the surface.

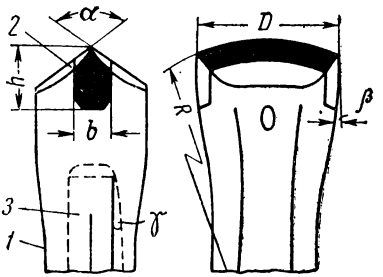
12.2. Percussive Boring Tools

When blast-holes and boreholes are made by percussion, the drill bits used have welded-on carbide tips.

The bit impacts are delivered from the drill piston through a composite borer. The borer consists of several rods, joined

Fig. 12.1. Bits for percussion drills

1 — body; *2* — carbide tips; *3* — cone; $\alpha = 110°$; $R = 180$ mm; $h = 18$ mm; $b = 10$ mm; $\beta = 3°$; $\gamma = 3°30'$



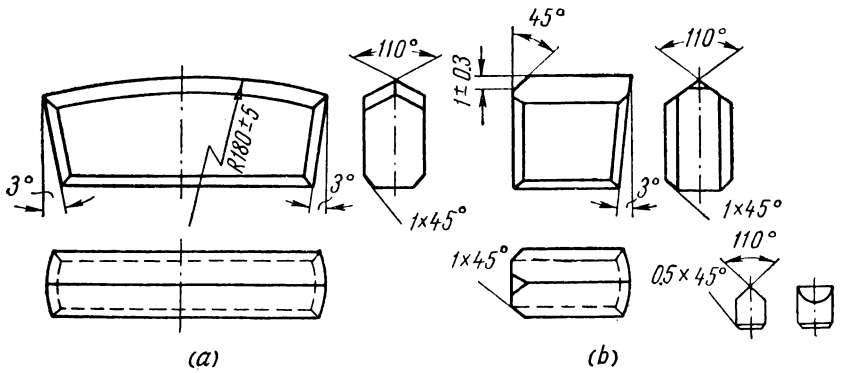


Fig. 12.2. Shapes of carbide inserts for tipped bits

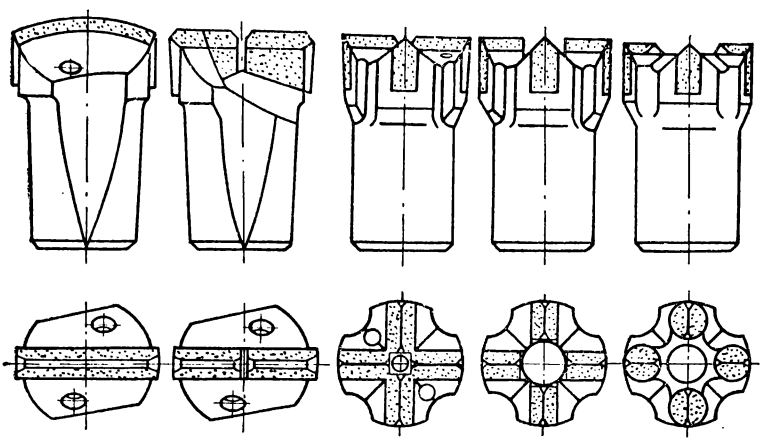


Fig. 12.3. Boring bits for drilling

by couplings; the piston impacts act against the tail piece, which transmits the percussion energy to the bit.

The boring bit for the drills (Fig. 12.1) consists of body *1*, to which carbide tip *2* is soldered. In the lower part of the body there is cone *3* by which the bit is joined with the rod.

The main parameters of the bits change with their designation. Bits are manufactured with various diameters: single-cutter chisel bits 28-52 mm in diameter and cross-shaped bits 32-43 mm in diameter.

The crown angle α of the bit is 110°, the sharpening radius of the working blade of the bit, is 180 mm. The height h

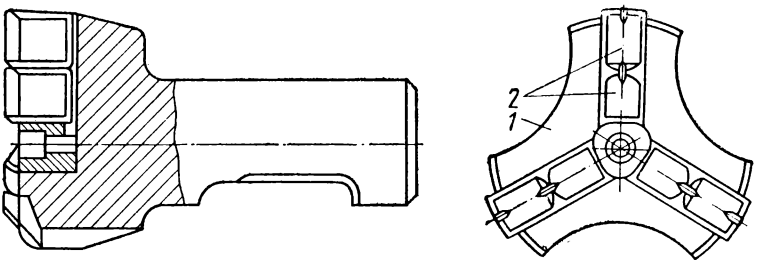


Fig. 12.4. Three-blade (three-point) bit
1 — body; *2* — carbide tips

of the carbide tip, is 18 mm, the width b is 10 mm. The sharpening angle β of the side face is 3°, the taper angle γ of the bit connection with rod is 3°30′.

For drilling the blast-holes, the tool industry manufactures boring bits reinforced with carbide tips having one (Fig. 12.2,*a*) or four (Fig. 12.2,*b*) blades. For reinforcing the bits rectangular carbide tips or cylindrical pins are used.

The main types of boring bits for drills are given in Fig. 12.3.

For boring holes by the percussion-rotary method with the help of pneumatic percussion drills, three or four-blade bits are used. The three-blade (three-point) bit (Fig. 12.4) is intended for making 105 mm dia boreholes, and the four-point bit — for making 155 mm dia boreholes (Fig. 12.5). These bits in contrast to bits for the drills have a tail piece,

which directly enters the body of the pneumatic percussion drill.

Carbides are used to reinforce the percussion and percussion-rotary action boring bits. The rods for the drills are made of hexahedral or round steel.

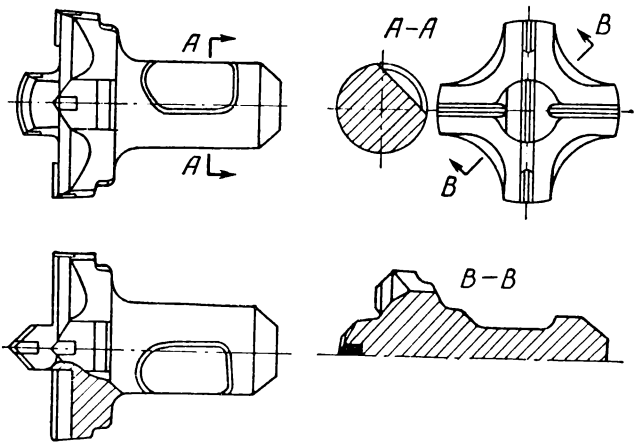


Fig. 12.5. Four-point bit

The percussion and percussion-rotary drilling methods with percussion drills and pneumatic-percussion drills are used for making blast-holes and boreholes mainly in hard and very hard rocks of a rupture strength of 10 to 20 according to the Protodiakonov scale. In fissured rocks three- or four-point boring bits are generally used to reduce vibration and prevent jamming of the tool.

12.3. Rotary Boring Tools

When blast-holes and bores are made by the rotary method, drills, cutter machines and core drilling machines are used.

In rotary boring with drills, the carbide-tipped cutting tool is driven by a pneumatic or electric motor through rods. The rock is destroyed by the cutter. Drill boring is carried out in soft and slightly harder rocks, coal, shale, etc.

Rotary boring with cutter machines is used for cutting of soft and medium, and recently, also of hard rocks. The rock is destroyed by the rotary and linear movements of cutters along the hole face. The cutters are rotated by an electric motor through a string of boring pipes. The force of axial pressure is up to 20-40 tons.

In core drilling the rock is destroyed along the ring circumference and a column of rock remains inside, called the core. It is periodically removed from the hole by a core-lifter, or by wedging the core in the core apparatus with stone or glass. Core drilling is carried out by bits reinforced with hard alloys or diamonds. Rotation is transmitted from a motor along the drilling pipes to the bit, a considerable axial load being applied.

CUTTING TOOLS FOR ROTARY BORING

In rotary boring by electric or pneumatic drills, the rock is destroyed by the cutting tool, fixed onto the boring rod.

The cutting tools for rotary drilling are made of carbon steel. Carbide tips are brazed onto the body of the cutting tool. The cutters are detachable and may be freely removed from the rod. The cutters are distinguished as coal and rock cutters, i.e., cutting tools for boring in coal or rock. The coal cutter, which works in a softer rock, has a smaller cutting area, while the rock cutter has a larger cutting surface.

Cutting tools (Fig. 12.6) usually have two points between which a crosscut is made; the aperture angle ψ, crosscut width d_p are chosen depending on rock hardness.

The cutting edges of the cutters are formed by the crossing of front and rear edges; each point has two cutting edges: the main and the auxiliary (or crosscut) edge.

The front edge of the tool is the area which, in the course of boring, removes chips of the rock.

The geometry of the cutter is characterized by the sharpening angle γ, back clearance angle α, front angle of cutting edge β, cutting angle δ, aperture angle ψ, taper angle σ; and angle φ, angle φ_1 at the front vertex, and angle φ_2 at lateral vertex.

The angle γ of sharpening is formed by the front and rear edges of the point. The rear angle α is the angle between the rear edge of the point and the cutting plane. Usually, the angle $\alpha \leqslant 20°$. The front angle β is the angle between the front edge of the cutting tool and the plane A, perpendicular to the cutting plane. The front angle β may be

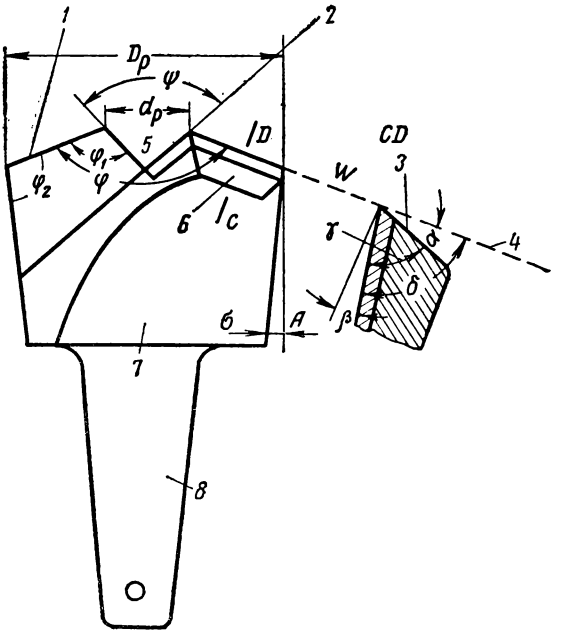


Fig. 12.6. Cutting tool for rock drilling
1 — main cutting edge; *2* — auxiliary cutting edge of crosscut; *3* — rear face; *4* — cutting plane; *5* — crosscut; *6* — point; *7* — body; *8* — tail piece

positive, when the cutting angle is less than 90°, and negative, when the cutting angle δ is greater than 90°.

The cutting angle δ is the angle between the front edge of the point and the cutting plane. The end angle φ is formed by the extension of the main cutting edges of the points. The angle φ_1 at the front vertex of the points is formed by the conjunction of the main cutting edge with the auxiliary edge.

The angle φ_2 at the lateral vertex of point is formed by the conjunction of the main edge and the generatrix of the drill body. The angle of crosscut ψ is formed by crossing the auxiliary cutting edges. The taper angle of the cutter body σ is necessary to reduce the friction between the body of the tool and the wall of the blast-hole.

BITS FOR COAL CUTTING MACHINES

Various types of coal-cutter are used for cutting coal. The working chain of the coal cutters has bits, which

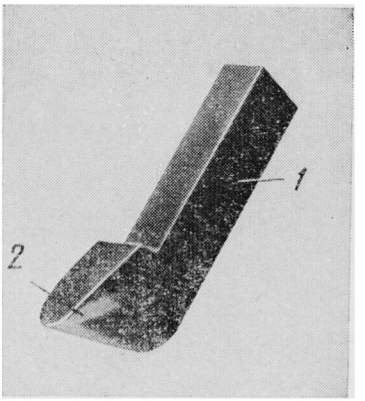


Fig. 12.7. Coal cutting bit

are spaced along the chain. When the chain moves, the bits bite into the soft rock or coal and undercut them.

A bit consists of body *1* with carbide tips *2* brazed in (Fig. 12.7).

CUTTER CHISELS

A cutter chisel (Fig. 12.8) consists of a frame and cutters, fixed on the frame with the help of a multi-row bearing support. The upper part of the chisel frame has a threaded nipple joined to the boring pipe. The rotation of the boring pipe is transmitted to the frame of the chisel and to the

cutters. The frame of the chisel consists of separate lugs welded together.

The cutters are made in the form of a cone; their external surface is reinforced with bits. When the cutters rotate,

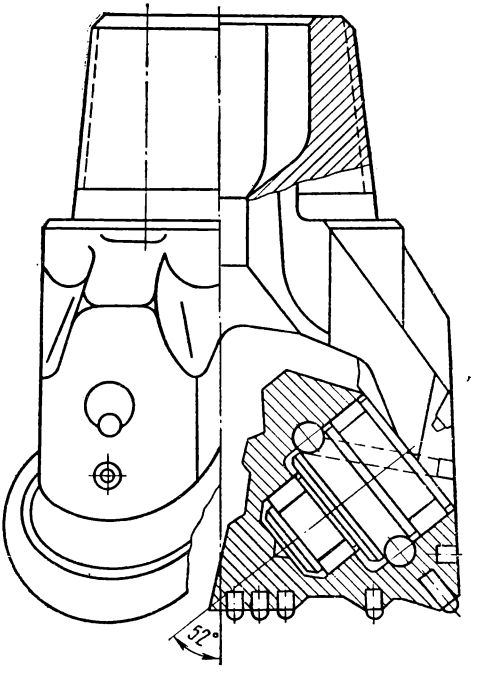


Fig. 12.8. Cutter chisel

their bits roll onto the bottom, catch the drift surface and destroy the rock.

Low-carbon alloy structural steel is used to make the cutters which are later carbonized to a depth of 1.5-2.0 mm and hardened. The Rockwell hardness of cutters should be 57-62 scale *C*.

Chromium-nickel-molybdenum steel is used for making the lugs. The surface of the lugs is cemented to a depth of 1.5-2.2 mm and hardened to Rockwell hardness 58-60 scale *C*.

The rollers and balls of the bearings are made of high-grade steels. After hardening the Rockwell hardness of the rollers and balls should be equal to 53-60 scale *C*.

For reinforcing the cutters, a carbide is used. The industry manufactures various types of cutter chisels for various designations.

According to the mode of rock destruction in the drift the chisels are divided into those for boring in continuous drifts (making service bores) and those for boring with a ring bore (exploration boring with lifting of core).

The boring chisels may have one, three or four cutter heads.

Single-cutter chisels are not used widely because they are not stable in operation and because of deviation of the bore. The diameter of single cutter chisels is usually small.

Two-cutter chisels have a stronger support for the cutters and a much larger diameter.

The most extensively used are three-cutter chisels, they are stable in service and have a high mechanical strength.

Four-cutter chisels are the most stable in drilling and permit the arrangement of the large number of bits. They can withstand large axial forces therefore the chisels are used for hard rock drilling.

The diverse service conditions require many types of chisels: serrated, serrated and pin, and pin-type bits.

A serrated bit has steel teeth, which, are cut in the body of the cutter. These bits are used for making holes in soft and medium rocks.

Pin-type bits have cutter teeth in the form of hard cylindrical inserts pressed into the cutter.

Bits with carbide inserts are used for making holes in medium and strong rock.

The serrated and pin bits have steel and hard-alloyed teeth.

BORING CORE BIT

The boring tools for rotary core boring consist of a carbide or diamond core bit, core barrel, adapter for core barrel to rods and the boring rods.

The boring bit (Fig. 12.9) has castellated ring *1* with a wall thickness equal to 6.5-8 mm, the working side of which is reinforced with carbides *2* or diamonds. In the lower part the bit has thread *3*, by which it is joined to the core barrel, and the latter being connected to the rod reducer.

Carbide tips of various shape are used to reinforce the bits for drilling rocks of various hardness.

For drilling hard rocks the octahedral rods 5 ± 0.3 mm in diameter and 10 ± 0.5 mm long are used. Each rod has a mass of 3 grams. When drilling medium and higher

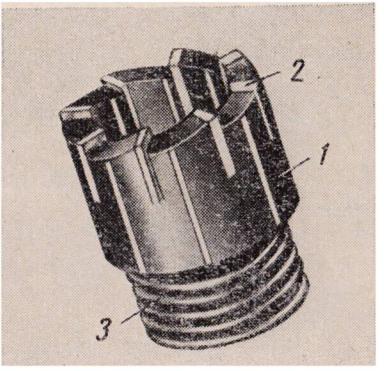


Fig. 12.9. Boring core bit

than medium hard rock, rectangular plates 10 ± 0.5 mm long, 7.5 ± 0.4 mm wide and 3 ± 0.3 mm thick are used, with a mass of 3 grams each.

For drilling rocks of medium hardness and also soft rocks, oblique-carbide tips are used with a mass of 3.3 grams. Also for drilling soft rock rhomb-shaped carbide tips are used with one side equal to 8.5 ± 0.5 mm and the other to 3 ± 0.3 mm.

Octahedral carbide rods are fixed in the bit ring with the cross rib protruding 0.75-1.0 mm beyond the external and internal side surfaces and elevated 1.5-2.5 mm above the butt end. To fix the bit ring, octahedral rods are calked into the bit; plates of other shapes are usually brazed in.

After assembling the bit the carbide tips are sharpened to an angle of 40-85°.

The core-boring bit may be fitted both with carbide tips and diamonds. For this purpose small diamonds are used with mass of hundredths of a carat.

The small-diamond bits for core-boring are termed cast-set or saturated depending on how they are made. When making cast-set bits the small diamonds are placed into a carbon or mica mould and filled with a metal alloy, which fixes the diamonds, with their cutting faces in a definite direction.

An alloy with a low melting point (alloys of copper, aluminium, nickel, cobalt) is usually selected to avoid the graphitization of the diamonds. After sintering, a cutting ring is obtained, which is soldered to the butt end of the annular bit. The cast bits are usually made of larger diamonds and used for boring less hard rocks.

Saturated diamond bits are made as follows: small diamonds with a fine carbide powder are sintered under a high pressure. While preparing for sintering, the diamonds may be placed at the bottom of the press mould or mixed with the carbide powder; in the first case the diamonds will be located only on the butt end of the cutting ring; in the second case they will be distributed over the entire mass of the ring. The carbide used is a powdered mixture of tungsten, cobalt, copper, nickel, ferrochromium, molybdenum in various proportions and combinations. The cutting ring formed after sintering is soldered to the ring with an alloy of copper and zinc or in some cases by mechanical fixing, for example, with cotter pins.

Saturated bits have a higher toughness than cast bits, which increases their wear-resistance.

Small-diamond bits may be of the following types:

(a) core (annular) bits with a continuous cutting ring and segmental ones;

(b) non-core bits: continuous (concave, straight, convex) and stepped.

Core bits are generally used for drilling holes in hard and very hard rocks. The drilling length per one small-diamond bit to full wear depends on the hardness and abrasiveness of the rock and ranges from 5-6 to 90-120 m and in soft limestone up to several thousand metres.

12.4. Maintenance of Drilling Tools

The proper maintenance of carbide drilling tools is an important factor for their efficient use, and therefore the following maintenance rules should be adhered to. Since drilling tools work in difficult conditions under impact loads, the requirements for the quality of carbide tips are very rigid.

The grade of carbide is selected depending on the method of drilling, on the equipment used, and the hardness of the

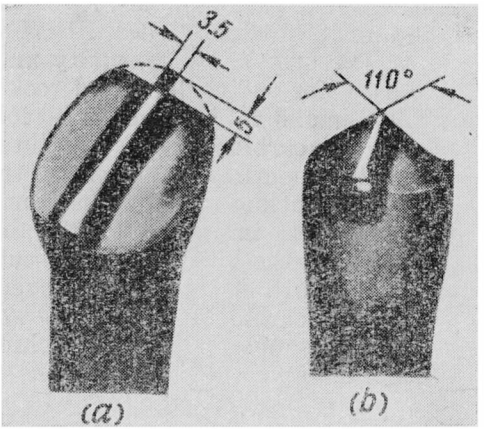


Fig. 12.10. Permissible wear of drilling bit (*a*) and angle of sharpening (*b*

rock to be drilled. The main principle for the selection of carbide grade is that the greater the rock hardness, the tougher the carbide.

Single-flat form of bit is more effective, but it cannot withstand high impact loads, and therefore percussion mechanisms of great power require the use of cross bits. When drilling fissured rock, it is necessary to use a multi-blade tool, as single-cutter bits may be jammed.

To bore the blast-holes, it is necessary first to use a borer, and then to drill with a bit, the compressed air pressure

being gradually raised. In the process of boring, the blast-hole is cleaned with compressed air or water.

It is also very important to resharpen the drilling tool in time. Ill-timed resharpening of the carbide tip leads to its early destruction, and to lower drilling speed.

The frontal wear appears in the form of a gradually widening almost horizontal surface on the blade with a slight rounding of angles. In the course of drilling, the bit is dulled and a blunted area is formed. Resharpening of bits leads to a gradual reduction in height of carbide tips. The minimum permissible height of carbide tips, when the bit is completely worn out, is usually 5-6 mm.

The sign of diametrical wear is a gradual decrease of the bit diameter in drilling. This kind of wear is encountered when drilling abrasive rocks. To ensure normal maintenance of the bits it is necessary to resharpen the bits both along the blade and over the diameter.

The single-blade boring bit is considered blunt when the bluntness surface of the carbide tip is 3.5 mm, at a distance of 5 mm from its edge, this being measured with a special gauge. After resharpening, the bit blade should have a bluntness surface of $0.5 + 0.5$ mm, a crown angle of 110°, a blade radius of 180 mm, a tapering angle of 3° (Fig. 12.10).

When sharpening multi-blade boring bits, it is additionally required to maintain the equality of all the blades in height and diameter.

Simple grindstones are used for sharpening the boring tools.

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